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SURVEY OF

DEVELOPMENT AND USE OF RAYON

AND OTHER SYNTHETIC FIBERS

By

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SURVEY OF DEVELOPMENT AND USE OF RAYON AND OTHER SYNTHETIC FIBERS [1]

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INTRODUCTION

Farmers in the United States have several good reasons for carefully studying the production of synthetic fibers in this country and abroad. Rayon, the most important of these synthetic fibers, has already displaced considerable quantities of both cotton and wool, as well as silk, for use in clothing and household fabrics. It is now also proving to be an important competitor in certain industrial uses. For example, in the field of tire fabrics, the largest single use for cotton in the United States, rayon is now being used extensively for certain classes of military vehicle and airplane tires as well as for large size commercial truck and bus tires. On the other hand, it is significant that some of the raw materials used in making synthetic textile fibers are obtained from farm products, such as cotton linters, casein, and soybeans, and the possibility of using other farm products has been given consideration.

In a general way most people are aware of these facts, but the information is rarely available in a form that will enable one to determine with any degree of accuracy the real status of synthetic textile fibers. One often hears that there will soon be little use for cotton, wool, and silk, and then again that synthetic textiles occupy only a small part of the textile field and can never displace cotton and wool in the bulk of their uses. Unless the layman knows certain basic facts relating to textiles in general, and to synthetic fibers in particular, he cannot give proper weight to such conflicting statements. It is the purpose of this report to present information to meet this need. Although it contains little new material, it brings together in an easily assimilable form the gist of a large amount of widely scattered information, both published and unpublished.

1/ Supersedes Mimeograph Circular MC-38 entitled "Report on Development and Use of Rayon and Other Synthetic Fibers," prepared by the following committee appointed by the Secretary of Agriculture: Carl H. Robinson, Chairman, and Robert J. Cheatham, Bureau of Agricultural Economics, and D. F. J. Lynch and H. P. Holman, Bureau of Chemistry and Soils (October 1938).

2/ Acknowledgement is made of the assistance given by original committee members, by other staff members of the United States Department of Agriculture, and by many individuals in the rayon industry.

Obviously, no one can say with certainty what the future holds for synthetic fibers. Those who do speculate upon their future generally predict that it will be bright. This report is concerned primarily with current developments and only indirectly with the future, but it is hoped that the information here presented will help agricultural research and extension workers, farm organizations, farmers themselves, and others to predict the impact of future developments in the field of synthetic fibers upon the consumption of farm products.

RAYON

The commercial production of rayon 3/ as a textile fiber began in France in 1884 and was quickly taken up in Germany and England and a little later in other European countries. Many difficulties of a technical nature were experienced during these early years, but they were finally overcome to the extent that by 1900 the commercial future of rayon was definitely assured. In the United States, uninterrupted commercial production did not begin until 1911, one or two unsuccessful ventures into this field having been made between 1900 and 1910. From this time, with the exception of 1932, 1934, and 1938, when slight declines occurred, production in this country has increased each year by substantial amounts.

What rayon is - Rayon is essentially a chemical product that owes many of its advantages to the fact that many of its finished properties can be predetermined by direct control during its manufacture. The term "rayon" properly applies to all types of synthetic fibers for which cellulose is the basic raw material. It is both interesting and important that cellulose is a substance that is present, to some extent, in almost all forms of vegetable matter. At present, spruce, western hemlock, southern pine, and cotton linters are the most economical sources of cellulose suitable for making rayon in the United States, though it is possible to obtain chemically satisfactory cellulose from many other different plants and trees.

Three principal processes for making rayon are now in commercial use. Essentially, however, the principle followed in each process is to treat a batch of cellulose, obtained by purification of wood or cotton linters, with certain chemicals to produce a liquid which is forced through tiny holes in a "spinneretto" and solidified in filaments to form rayon. Within wide ranges, the chemical and physical properties possessed by the finished rayon are largely determined by the particular process employed.

3/ During its early history, what we now know as rayon was generally called artificial silk and sometimes art silk. The term "artificial silk" led to so much confusion and misunderstanding in both retail and consumer circles that the National Retail Dry Goods Association of the United States set up a committee, about 1924, to select a new and more appropriate name. The name "Rayon" was chosen and has since been generally accepted.

Rayon is used in two principal forms: (1) continuous filament rayon (often referred to as simply filament rayon, or rayon yarn) and (2) staple fiber rayon (generally called rayon staple fiber). Staple fiber differs from continuous filament rayon in that it is composed of fibers of a certain definite length (from about 1 to 8 inches or longer, depending upon the use to which it is to be put). Limited quantities of rayon are produced also in forms that resemble straw, horsehair, and other materials.

MANUFACTURING PROCESSES

The three principal processes by which rayon is made are (1) the viscose, (2) the acetate, and (3) the cuprammonium. A fourth, the nitrocellulose, the first method by which rayon was produced successfully on a commercial scale, was once of considerable importance, but today it is of little more than historic interest. The world production of this type of rayon has declined to negligible quantities. The term "viscose rayon" designates rayon made by the viscose process, and similarly for the others.

Viscose process - For the ten years preceding the present war (1929-38), between 80 and 90 percent of the total filament rayon and an even higher percentage of the staple fiber produced throughout the world, were made by the viscose process. In the United States, the proportion made by the viscose process was considerably lower. In 1927, about 90 percent of all the rayon produced in this country was viscose rayon, whereas in 1943 only about 70 percent was of this type. 4/ In the United States production of acetate rayon has increased at a more rapid rate than has production of viscose rayon during recent years.

From shortly after the beginning of rayon manufacture until about 1925, wood pulp was almost the only source of cellulose used in the production of viscose rayon. Consumption of cotton linters in this type of rayon then increased somewhat until 1933, but thereafter declined until by 1937 only negligible proportions were used. Linters continue to be used in the viscose process, however, for special products, such as high-strength types of rayon and very fine rayon yarns.

To produce rayon yarn by this process, sheets of wood pulp or cotton linters, which have been previously purified and prepared, are placed in the perforated compartments of a steel tank, where they are steeped in a strong caustic soda solution. After steeping, the swollen pulp sheets are subjected to hydraulic pressure to expel the excess alkali. The pressed alkali cellulose next is shredded into crumbs and packed in closed containers to mature, or age, at a constant temperature for a definite time. The aged crumbs are then mixed with carbon bisulfide, which converts them into cellulose xanthate.

4/ Percentages are based on total rayon produced. On a poundage basis, trends in the production of viscose rayon have been sharply upward. See section "Trends in Production."

Currents of air remove the excess carbon bisulfide, and the crumbs, now yellow in color, are ready for further treatment. The xanthate is dissolved in a weak caustic soda solution in a large tank equipped with rotating paddles, forming a highly viscous solution called "viscose." The undissolved fibers and small particles of foreign matter are removed by forcing the viscose through several cloth filters. It is then pumped into storage tanks and, after aging, the air bubbles are removed and it is ready for "spinning."

The viscose solution is pumped to the spinning machines, where it is forced through small holes in metal spinnerettes and drawn through a coagulating acid bath, which usually consists of a solution of sulfuric acid containing some glucose, sodium sulfate, and other salts. The metal spinnerette, which is usually made of platinum in combination with other precious metals, contains as many holes as the number of filaments desired in the yarn. The viscose solution solidifies or coagulates as it is forced out into the bath, and the filaments are thrown or formed into cakes by the centrifugal pot system or wound on bobbins. In the centrifugal pot system which is largely used in this country, some twist is imparted to the yarn as it is laid into the pot. The yarn is next removed from the pot in cake form and washed, desulfurized, bleached, and dried. It is then conditioned to the proper moisture content, after which it is wound on cones or tubes or made into skeins, as desired by the purchaser. Chemically, viscose rayon is nearly pure, regenerated cellulose.

Several manufacturers of viscose rayon specially process part of their output to produce "high-tenacity" yarns or yarns having greater tensile strength than the ordinary product. An essential part of this processing is the use of special means of stretching or drawing out the filaments as they are spun. By varying the amount of stretch, the tensile strength and inversely the extensibility (stretch) can be varied over a considerable range.

Manufacture of staple fiber by the viscose process is essentially the same as for continuous filament yarn up to the spinning stage. At this point, spinnerettes with 500 to 3,000 or even more holes are used rather than spinnerettes with 16 to 150 holes, such as are generally used in production of continuous filaments. As they emerge from the coagulating bath, filaments from a number of spinnerettes are combined to form a continuous "tow" or untwisted rope, which is then processed in one of two ways. It may be cut into the desired staple length and then washed, desulfurized, and bleached, or the procedure may be reversed and the "tow" given these aftertreatments before it is cut.

Acetate process - In world production, acetate rayon ranks a poor second to viscose rayon. About 17 percent of the world production of filament rayon (but a considerably smaller percentage of the production of staple fiber) was made by the acetate process in 1940, as compared with 4 or 5 percent in 1927. As in the case of viscose rayon, the proportion for the United States was somewhat different. In 1927, about 7 percent of the total rayon produced in the United States was manufactured by the acetate process, a proportion not widely different from that for the entire world, but in 1934 and 1943, the percentages were 18 and 28, respectively, showing a marked and well-sustained gain.

Until about 1940, the only source of cellulose used in acetate rayon was linters, but now wood pulp is also used for this purpose. In making acetate rayon, the purified linters or wood pulp is first converted into primary cellulose triacetate by the use of acetic anhydride, glacial acetic acid, and a catalyst, which is frequently sulfuric acid. This process is conducted in enamel-lined tanks under a controlled temperature. Diacetate acetate of cellulose, or secondary cellulose acetate, is then obtained by hydrolyzing the triacetate, and this is precipitated as a white flocculent mass by pouring the fluid into water. The weight of the cellulose product is increased materially by this conversion to an acetate ester of cellulose, the weight of the yarn or fiber frequently being 60 percent greater than that of the cellulose used in its production. The cellulose acetate is then dissolved in acetone to form the spinning "dope," which is filtered and stored.

The acetate spinning solution is forced downward through the holes in a spinnerette set vertically at the top of a tall, narrow shaft. A current of warm air rises through the shaft, causing the filaments to solidify by the evaporation of the acetone as they pass downward. This method is termed "dry" spinning, in contrast to the "wet" spinning process used in the manufacture of viscose yarns. Rayon made by the acetate process is not regenerated cellulose, but, as its name implies, is an acetate ester of cellulose. Its chemical and physical properties are different in many respects from those of pure cellulose.

As in the viscose process, special means may be taken to stretch and otherwise treat acetate filaments in order to obtain yarns having greater tensile strengths than usual. A special type of yarn made by one of the acetate rayon producers has the greatest strength of any rayon manufactured but is reported to be chemically modified by a saponification process in its manufacture, so that it is no longer acetate rayon but is instead, a type of regenerated cellulose.

Cuprammonium process - The cuprammonium process of manufacturing synthetic yarns originated in Germany in 1898. Only a very small proportion of the total rayon yarn manufactured in the United States, and only about 4 percent of the world production of rayon yarn, is made by this method. Until recently, cotton linters were the source of cellulose for this process, but it is reported that highly purified wood pulp now is being used also. Copper sulphate and ammonia are used to dissolve the cellulose, yielding a solution which is filtered several times and thinned until it is suitable for spinning. The solution is then forced through the orifices of the spinnerette into a stream of deaerated water flowing through a glass funnel. Coagulation occurs slowly, and the increasing velocity of the water as it passes through the funnel stretches the still plastic yarn. From this stretching action the system derives its name of "stretch spinning." From the funnel, the yarn passes through an acid-setting bath after which it is washed and prepared for shipment. Most of the ammonia and copper used in preparing the spinning solution is later recovered from the water used in the spinning and washing and from the acid-setting bath.

Nitrocellulose process - The nitrocellulose process, also called the "Chardonnet" process, was invented by Count Hilaire de Chardonnet. This was the first process used in producing synthetic textile fibers on a commercial scale, but no rayon has been produced in the United States by this method since June 1934, and less than 1 percent of the world production of rayon yarn was being made by it at the beginning of World War II. Cotton linters are used exclusively as a raw material in this process, although at one time small quantities of other materials were also used. The cleaned linters are converted into nitrocellulose by sulfuric and nitric acids. After the nitrocellulose has been thoroughly washed, it is dissolved in a mixture of alcohol and ether, forming a viscous solution, which is filtered and used for the spinning solution. The solution is forced through spinnerettes and coagulated by evaporation of the solvents. The product is denitrated by treatment with a solution of ammonium sulfide, leaving a regenerated cellulose yarn. 5/

TRENDS IN THE PRODUCTION OF RAYON

Total world production of all types of rayon increased rapidly during the period 1920 through 1942, increasing at an average rate of 32 percent per year from 1920 through 1929 and 18 percent per year from 1930 through 1942 (table 1). Even during the world-wide depression beginning in 1929, production rose more than 20 percent from 1929 to 1932. Beginning with 1933, production was again greatly stimulated; in 1937 it was 240 percent greater than in 1932. A less rapid but continued advance took place during the immediate pre-war and wartime period from

5/ Rayon Year Book, 1928-29, p. 29. Published by the Textile World, New York.

Table 1. - Production of continuous filament rayon and rayon staple fiber, in World and in selected countries, 1911-42

Year	United States	Japan	Germany	Italy	Great Britain	France	Other	World Total	Percentage change from preceding year
	Million pounds	Million pounds	Million pounds	Million pounds	Million pounds	Million pounds	Million pounds	Million pounds	Percent
1911	.4	-	1/	1/	1/	2.6	15.7	18.7	
1912	1.1	-	1/	1/	1/	2.9	15.8	19.8	5.9
1913	1.8	-	7.7	.3	6.6	3.3	5.5	25.2	27.3
1914	2.4	-	3.5	1/	4.0	2.0	7.8	19.7	-21.8
1915	3.9	-	2.2	1/	4.0	.9	7.5	18.5	- 6.1
1916	5.8	-	5.5	1/	3.5	1.6	7.0	23.4	26.5
1917	6.5	-	6.6	1/	3.8	1.2	6.1	24.2	3.4
1918	5.8	.1	8.8	.4	3.0	1.4	6.4	25.9	7.0
1919	8.3	.1	7.7	.7	4.8	1.8	4.4	27.8	7.3
1920	10.1	.2	5.2	1.6	6.0	3.4	6.6	33.1	19.1
1921	15.0	.2	7.7	3.2	9.0	4.4	8.7	48.2	45.6
1922	24.1	.5	11.0	6.6	14.5	6.8	13.1	76.6	58.9
1923	35.0	.8	14.3	11.0	17.0	7.7	17.2	103.0	34.5
1924	36.3	1.4	23.2	17.6	24.7	13.2	21.9	138.3	34.3
1925	51.0	3.2	26.0	30.8	29.8	14.3	30.2	185.3	34.0
1926	62.7	5.0	24.7	36.8	25.5	19.2	37.8	211.7	14.2
1927	75.6	10.5	41.3	53.8	38.8	24.2	50.9	295.1	39.4
1928	97.2	16.6	48.9	57.3	52.1	29.9	58.5	360.5	22.2
1929	121.9	26.0	60.8	73.0	55.3	41.8	62.6	441.4	22.4
1930	127.7	36.6	63.4	67.0	47.8	50.6	64.3	457.4	3.6
1931	151.8	48.3	66.3	75.6	53.5	44.5	67.8	507.6	11.0
1932	135.8	70.3	61.0	71.7	71.1	52.2	72.5	534.6	5.3
1933	215.6	99.3	71.6	84.4	82.5	59.2	78.7	691.3	29.3
1934	210.5	157.8	100.7	107.4	91.3	61.6	95.1	824.4	19.3
1935	262.2	237.9	135.6	153.4	121.5	66.5	103.5	1,080.6	31.1
1936	289.9	320.8	193.8	196.1	143.0	63.1	115.2	1,321.9	22.3
1937	341.9	508.6	344.2	262.9	152.4	77.7	131.5	1,819.2	37.6
1938	287.5	584.6	470.0 2/	268.3	138.2	72.6	124.7 2/	1,945.9	7.0
1939	379.9	548.8	600.0 2/	310.0	180.0	71.7	137.1 2/	2,227.5	14.5
1940	471.2	525.0	825.0	325.0	150.0	2/	84.6	2,380.8	6.9
1941 3/	573.2	-	1,223.0	-	-	110.0	-	2,780.0	16.8
1942 3/	632.6	700.0	1,100.0	462.0	135.0	197.5	245.8	3,472.9	12.5
1943	663.1	-	-	-	-	-	-	-	-

1/ Separate data not available. Production, if any, included under "other".
2/ Total for Germany includes production of Austria, 1938-42; Czechoslovakia, 1939-42; Belgium, France, Hungary, Netherlands, Norway, Rumania, 1940; Poland, 1940 and 1942.
3/ Data for 1941 and 1942 for foreign countries are estimates. Data for European countries for 1942 are from Bureau of Foreign and Domestic Commerce.

Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration. Compiled from Rayon Organon except foreign data for 1941, which are from Snia Viscosa, as quoted in Textile Colorist, August 1942, page 405. Production of rayon staple fiber prior to 1929 not included in these figures.

1938 through 1942, the total production for 1942 being about 90 percent greater than the total for 1937. World production of rayon in 1942 surpassed that in any previous year; more recent statistics are not yet available, but it was considered unlikely that this record would be equalled in 1943 because of destruction of Axis chemical and rayon plants and shortages of manpower and materials in all countries.

Production of rayon (including rayon staple fiber) for each of the six leading countries for the years 1920-1942 has been plotted in figure 1 to give a graphic comparison of the relative rates of growth in the different countries. A matter of considerable interest, which stands out sharply in figure 1, is the extremely rapid increase in the production of rayon in Germany and Japan. Production in Germany proper increased tenfold from 1934 to 1942. Production of rayon in Japan almost doubled every two years from the early 1920's until, in 1936, that country displaced the United States as the world's largest producer of rayon. Beginning in 1938, however, expansion of Japan's rayon industry stopped for a time, and in 1939 Germany replaced Japan as the largest producer of rayon.

Although on a percentage basis production of rayon in the United States is not now increasing as rapidly as it did during the earlier years of the industry (prior to 1930), the growth in actual quantities during the last few years has been unprecedented. From 1939 to 1943, the output increased 283 million pounds, an increase approximately equal to the entire production for 1936.

Although it is not possible to predict future trends from past production with much exactness, the prediction that the period of expansion of the rayon industry is at an end would not be justified. On the other hand, the rate of growth (that is, the percentage by which it is increasing each year) is already showing signs of slackening. The situation with regard to continuous filament rayon is quite different from that of rayon staple fiber, however, and for this reason trends in the production of the two kinds of rayon will be discussed separately.

Continuous filament rayon - Since there was no appreciable production of rayon staple fiber before about 1932, trends in production of continuous filament rayon up to that time were approximately the same as those shown in figure 1 for total rayon. Although the output of continuous filament rayon has increased tremendously since 1932, it has not increased as rapidly, percentagewise, as it did during the period of 1920-1929 (see table 2, last column), nor as much as production of staple fiber increased during the last few years. Uses for which continuous filament rayon is suitable are limited, and there are indications that many of them have already been fully exploited. Recent development of high-tenacity types of rayon, however, has made possible the use of continuous filament rayon for additional purposes, and is making possible further increases in its production.

Rayon staple fiber - Initial interest in staple fiber arose in Germany during World War I, owing to a shortage of cotton and wool for which it was used as a substitute, but lapsed with the cessation of hostilities when adequate supplies of the natural fibers were again available. Like continuous filament rayon, this early rayon staple fiber was expensive to produce and process, and its quality was inferior. A few years ago, interest in staple fiber was revived, first in Germany and Italy, where policies of self-sufficiency and lack of adequate supplies of cotton and wool, resulting principally from a shortage in foreign exchange, required the use of as large a quantity of domestically produced synthetic textiles as possible. As the potentialities of staple fiber were demonstrated, other countries became interested. Improvements in quality and reductions in price followed. Rayon staple fiber is now far more than a substitute; it is a textile fiber distinctly different from any other.

Without doubt, the sharply increased production and use of rayon staple fiber has been one of the most important developments in the history of synthetic textile fibers. From 1931 to 1942, world production increased from 8 million to about 2,000 million pounds (table 3 and figure 2), representing in 1931 less than 2 percent of the total production of all types of rayon and in 1942, only eleven years later, about 58 percent (table 4). In fact, the total increase in production of all types of rayon over this same period (table 1) is largely accounted for by this tremendous increase in the production of rayon staple fiber.

Although it is impossible to predict what new uses will eventually be found for rayon staple fiber, a still further increase in its production is likely during the next few years. Many early production and processing difficulties have been overcome, and many of its properties have been improved, thus increasing its potential use.

Production of Continuous Filament Rayon by Processes

Because different kinds and quantities of raw materials are used as sources of cellulose for making different types of rayon, trends in the production of rayon by processes are of some importance to producers of these raw materials. Statistics on such trends, however, are available only for continuous filament rayon.

World Production - Since 1929, viscose rayon has declined from 88 to 79 percent of the total world production of continuous filament rayon (table 5). Most viscose rayon is now made from wood pulp, although some linters are used for special types. In the meantime, the combined production of acetate and cuprammonium rayon has increased from 9 percent to 21 percent of the total. Cotton linters were the source of cellulose for these types of rayon in the United States prior to World War II but special grades of wood pulp now also are used. As pointed out in the section on processes of manufacture, production of nitrocellulose rayon is negligible today. Production of cuprammonium rayon over the period 1929-1940 has ranged from 2 to 4 percent of the total.

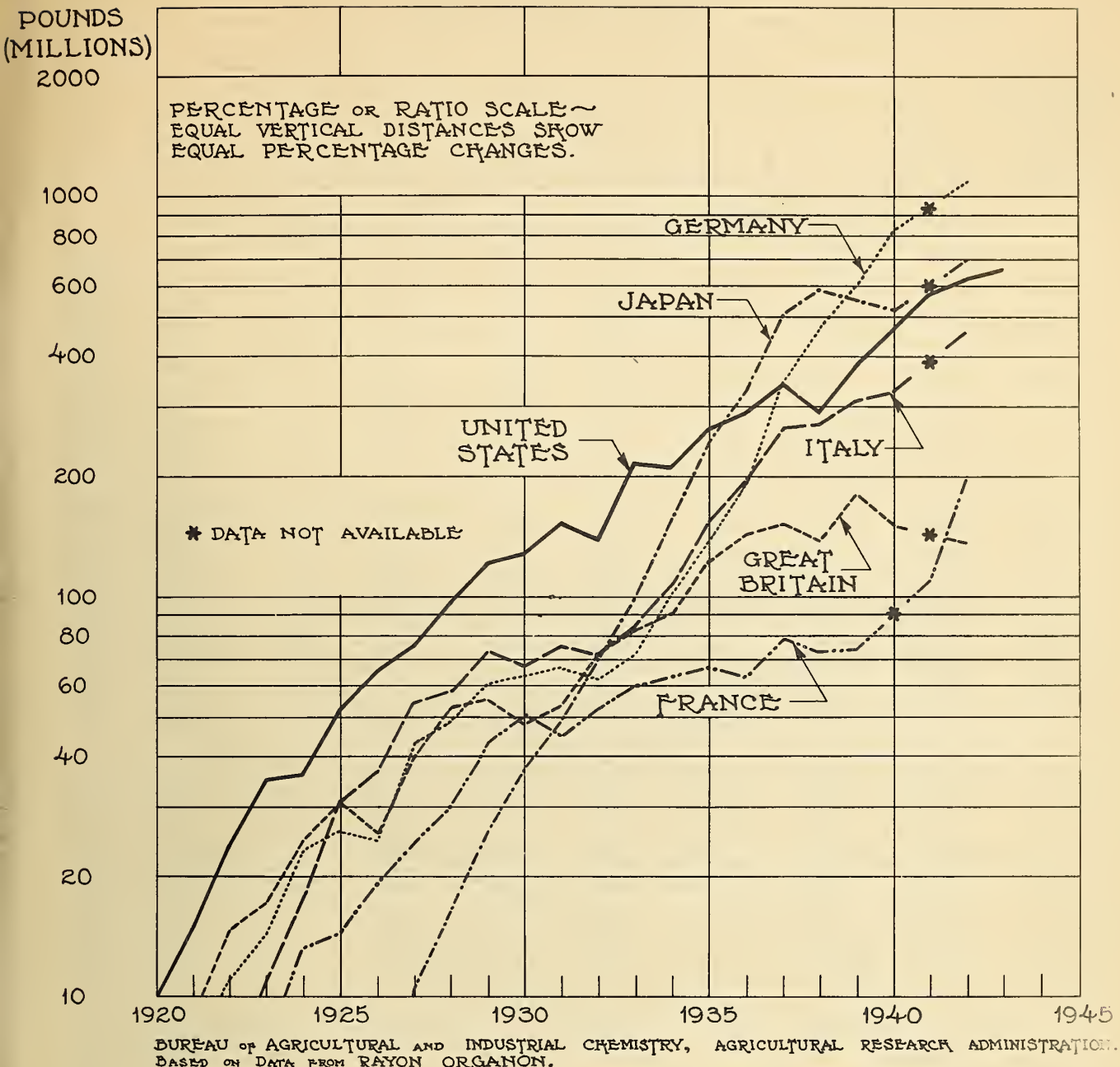


FIGURE 1. - PRODUCTION OF RAYON BY COUNTRIES, 1920-1942

Japan displaced the United States as the largest rayon producing country in 1936 but was itself replaced in this role by Germany in 1939. In both Japan and Germany there were extremely rapid increases in rayon production during the years immediately preceding 1939.

Table 2. - Production of continuous filament rayon in World and in selected countries, 1911-42

Year	United States	Japan	Germany	Italy	Great Britain	France	Other	World Total	Percentage change from preceding year
	Million pounds	Million pounds	Million pounds	Million pounds	Million pounds	Million pounds	Million pounds	Million pounds	Percent
1911	.4	-	1/	1/	1/	2.6	15.7	18.7	
1912	1.1	-	1/	1/	1/	2.9	15.8	19.8	5.9
1913	1.8	-	7.7	.3	6.6	3.3	5.5	25.2	27.3
1914	2.4	-	3.5	1/	4.0	2.0	7.8	19.7	-21.8
1915	3.9	-	2.2	1/	4.0	.9	7.5	18.5	-6.1
1916	5.8	-	5.5	1/	3.5	1.6	7.0	23.4	26.5
1917	6.5	-	6.6	1/	3.8	1.2	6.1	24.2	3.4
1918	5.8	.1	8.8	.4	3.0	1.4	6.4	25.9	7.0
1919	8.3	.1	7.7	.7	4.8	1.8	4.4	27.8	7.3
1920	10.1	.2	5.2	1.6	6.0	3.4	6.6	33.1	19.1
1921	15.0	.2	7.7	3.2	9.0	4.4	8.7	48.2	45.6
1922	24.1	.5	11.0	6.6	14.5	6.8	13.1	76.6	58.9
1923	35.0	.8	14.3	11.0	17.0	7.7	17.2	103.0	34.5
1924	36.3	1.4	23.2	17.6	24.7	13.2	21.9	138.3	34.3
1925	51.0	3.2	26.0	30.8	29.8	14.3	30.2	185.3	34.0
1926	62.7	5.0	24.7	36.8	25.5	19.2	37.8	211.7	14.2
1927	75.6	10.5	41.3	53.8	38.8	24.2	50.9	295.1	39.4
1928	97.2	16.6	48.9	57.3	52.1	29.9	58.5	360.5	22.2
1929	121.4	26.0	58.4	71.3	52.7	41.8	62.6	434.2	20.4
1930	127.3	36.6	59.0	66.3	47.0	50.6	64.4	451.2	3.9
1931	150.9	48.3	61.9	74.2	52.7	44.0	67.7	499.7	10.7
1932	134.7	69.8	58.0	62.3	69.9	50.6	72.0	517.3	3.5
1933	213.5	98.3	62.9	73.4	80.0	57.0	78.3	663.4	28.2
1934	208.3	153.1	84.9	85.8	88.9	57.2	94.3	772.5	16.4
1935	257.6	224.3	97.7	85.7	112.2	61.5	102.1	941.1	21.8
1936	277.6	275.0	99.0	86.0	116.8	59.5	109.4	1,023.3	8.7
1937	321.7	334.3	125.0	106.0	119.7	66.4	126.3	1,200.0	17.3
1938	257.6	209.6	140.0 2/	101.4	106.4	61.8	111.5 2/	988.3	-8.2
1939	328.6	239.[illegible]	160.0 2/	119.0	120.0	56.2	122.3 2/	1,145.5	11.6
1940	390.1	225.0	250.0 2/	100.0	100.0	2/	78.9 2/	1,144.0	0.1
1941 3/	451.2	-	-	-	-	-	-	1,300.0	13.6
1942 3/	479.3	300.0	220.0 2/	132.0	90.0	69.5	156.4	1,447.2	11.3
1943	501.1	-	-	-	-	-	-	-	-

1/ Separate data not available. Production if any, included under "other".
2/ Figures for Germany include production of Austria, 1938-42; Czechoslovakia, 1939-42; Poland, 1940, 1942; Belgium, France, Hungary, Netherlands, Norway, Rumania, 1940.
3/ Data for 1941 and 1942 for foreign countries are estimates. Data for European countries for 1942 are from Bureau of Foreign and Domestic Commerce.

Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration. Compiled from Rayon Organon except World estimate for 1941, which is from Snia Viscosa as quoted in Textile Colorist, August 1942, page 405.

Table 3. - Production of rayon staple fiber in World and in selected countries, 1929-1942

Year	United States	Japan	Germany	Italy	Great Britain	France	Other	World Total
	Million pounds	Million pounds	Million pounds	Million pounds	Million pounds	Million pounds	Million pounds	Million pounds
1929	.5	-	2.4	1.7	2.6	-	-	7.2
1930	.3	-	4.4	.7	.8	-	-	6.2
1931	.9	-	4.4	1.4	.8	.5	-	8.0
1932	1.1	.6	3.0	9.4	1.2	1.6	.4	17.3
1933	2.1	1.0	8.8	11.0	2.4	2.2	.4	27.9
1934	2.2	4.7	15.8	21.6	2.4	4.4	.7	51.8
1935	4.6	13.6	37.9	67.7	9.3	5.0	1.5	139.6
1936	12.3	45.8	94.8	110.1	26.2	6.6	2.8	298.6
1937	20.2	174.2	219.2	156.3	32.7	11.3	5.3	619.2
1938	29.9	375.0	330.0	166.9	31.7	10.8	13.3	957.6
1939	51.3	309.5	440.0 1/	190.0	60.0	15.5	14.7 1/	1,082.0
1940	81.1	300.0	575.0 1/	225.0	50.0	1/	55.7 1/	1,236.8
1941 2/	122.0	-	-	-	-	-	-	1,480.0
1942 2/	153.3	400.0	880.0 1/	330.0	45.0	128.0	89.4 1/	2,025.7
1943	162.0	-	-	-	-	-	-	-

1/ Figures for Germany include production of Czechoslovakia, 1939-42; Poland, 1940, 1942; Belgium, France, Rumania, 1940.

2/ Data for 1941 and 1942 for foreign countries are estimates. Data for European countries for 1942 are from Bureau of Foreign and Domestic Commerce. Data for 1942 for Germany, Italy, and France include casein fiber.

Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration. Compiled from Rayon Organon except World estimate for 1941, which is from Snia Viscosa as quoted in Textile Colorist, August. 1942, page 405.

Table 4. - Production of rayon staple fiber as percent of total rayon produced in the World and in certain countries, 1929-1942

Year	United States	Japan	Germany	Italy	Great Britain	France	Other	World Total
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
1929	.4	-	3.9	2.3	4.7	-	-	1.6
1930	.3	-	6.9	1.0	1.8	-	-	1.4
1931	.6	-	6.6	1.9	1.5	1.1	-	1.6
1932	.8	.8	4.9	13.1	1.7	3.2	.6	3.2
1933	1.0	1.0	12.2	13.0	3.0	3.7	.5	4.0
1934	1.0	3.0	15.7	20.1	2.7	7.1	.7	6.3
1935	1.8	5.7	28.0	44.1	7.7	7.5	1.4	12.9
1936	4.2	14.3	48.9	56.1	18.3	10.0	2.4	22.6
1937	5.9	34.3	63.7	59.5	21.5	14.5	4.0	34.0
1938	10.4	64.1	70.2	62.2	23.0	14.9	10.7	49.2
1939	13.5	56.4	73.3 1/	61.6	33,3	21.6	10.7 1/	48.6
1940	17.2	57.1	69.7	69.2	33.3	-	65.8	51.9
1941	21.3	-	-	-	-	-	-	53.2
1942	24.2	57.1	80.0	71.4	33.3	64.8	36.4	58.3
1943	24.4	-	-	-	-	-	-	-

Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration. Based on data given in tables 2 and 3.

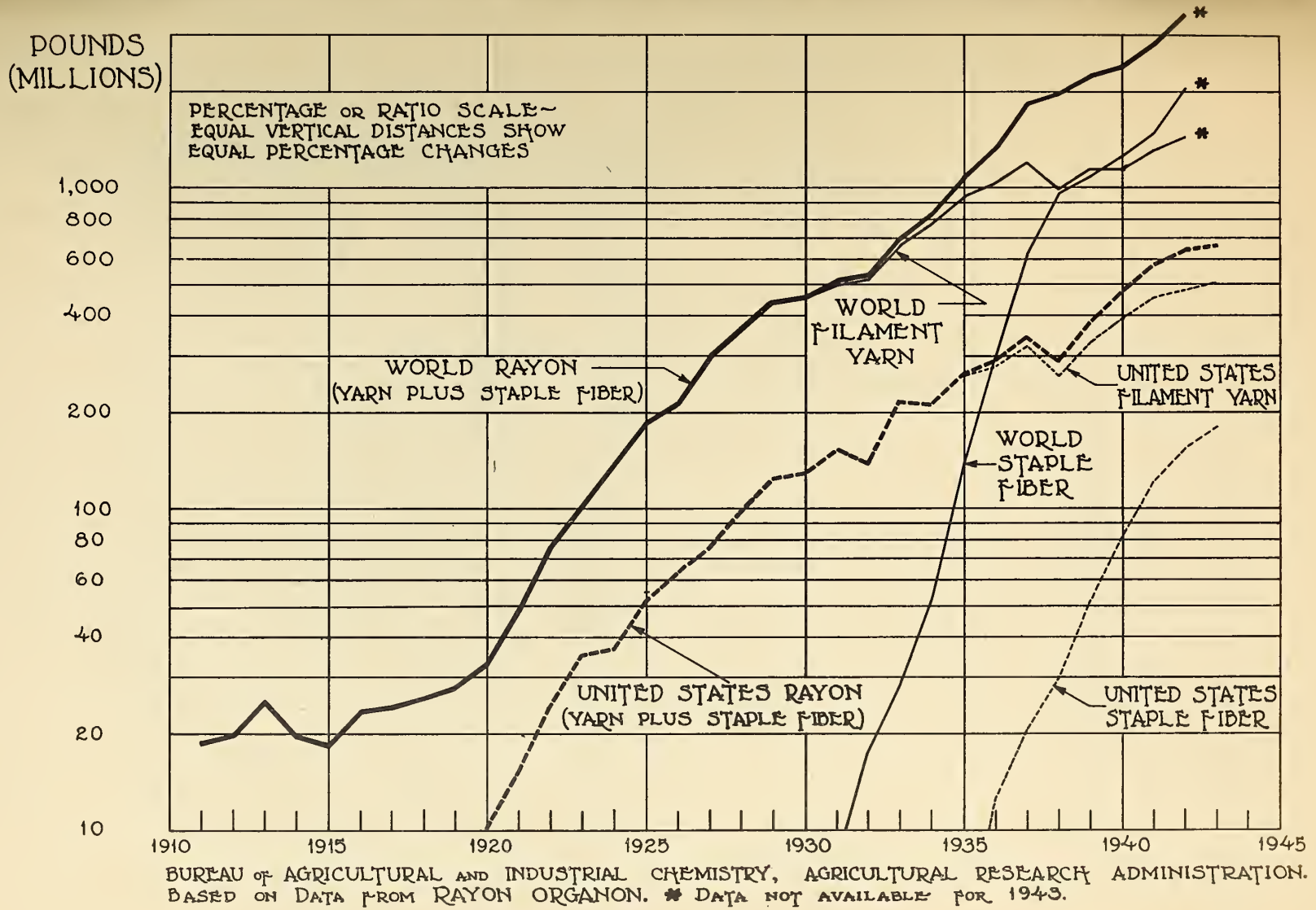


FIGURE 2. - TRENDS IN PRODUCTION OF RAYON IN WORLD AND IN UNITED STATES, 1911-1943

Until about 1930, almost all rayon produced was continuous filament yarn. Continued expansion in rayon production since then has been due in large part to rapidly increasing output of rayon staple fiber. Staple fiber comprised 52 percent of the rayon production of the World and 17 percent of the United States production in 1940 and 24 percent of the United States production in 1943.

Table 5.- Proportion of world production of continuous filament rayon made by various processes, 1929 through 1940

Year	Viscose	Cupram-monium	Nitro-cellulose	Acetate	Total
	Percent	Percent	Percent	Percent	Percent
1929	88	3	3	6	100
1930	88	3	2	7	100
1931	89	3	1	7	100
1932	88	2	1	9	100
1933	85	3	1	11	100
1934	86	4	-	10	100
1935	86	3	-	11	100
1936	85	4	-	11	100
1937	85	3	-	12	100
1938	82	4	1/	14	100
1939	81	4	1/	15	100
1940	79	4	1/	17	100

1/ Less than 1 percent.
Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration. From Rayon Organon for June 1938; June 1941.

United States production - To producers of raw materials for cellulose used in making rayon in the United States, the proportion of each type produced in this country is, of course, of more immediate interest. Of the three types of continuous filament rayon now produced in the United States, the acetate type has increased at a much faster rate in recent years than the other two, rising from about 7 percent of the total in 1929 to 36 percent in 1942, but then declining slightly to 32 percent in 1943 (table 6). Production by the cuprammonium process varied considerably over the same period; production in 1942 was greater than it was in 1929 but still represented less than 5 percent of the total. Production of viscose yarn, although substantially greater today than it was in 1929 on a quantitative basis, now constitutes a smaller proportion of the total than it did at the beginning of the period 1929-1942. This is almost entirely the result of the much more rapid increase in production of rayon yarn of the acetate type.

Table 6.- Proportion of United States production of continuous filament rayon made by various processes, 1929 through 1942

Year	Viscose and cuprammonium	Nitrocellulose	Acetate	Total
	Percent	Percent	Percent	Percent
1929	67	6	7	100
1930	88	4	8	100
1931	86	4	10	100
1932	81	5	14	100
1933	78	3	19	100
1934	80	2	18	100
1935	78	-	22	100
1936	77	-	23	100
1937	74	-	26	100
1938	70	-	30	100
1939	70	-	30	100
1940	66	-	34	100
1941	64	-	36	100
1942	65	-	35	100
1943	68	-	32	100

Partly estimated. Based on data from Rayon Organon.

SOURCES OF CELLULOSE

The cellulose used by the rayon industry of the United States is derived from special types of pulpwood and certain grades of cotton linters. Both pulpwood and linters are of interest to large segments of the population of the United States. The first is a product of forests in various sections of the country, and the other is a byproduct of one of the country's most important crops. The following discussion of present and potential sources of cellulose will be confined to a consideration of the raw material requirements of the rayon industry of the United States. It should be borne in mind, however, that part of the wood pulp used for rayon in this country is imported from Canada and also that moderate to large quantities of cotton linters and wood pulp suitable for rayon are normally exported.

Present Sources

Little is known about the proportions of different raw materials used as sources of cellulose for the rayon industry during its early history, but sufficient information is available to trace developments that have led to the present relative use of cotton linters and wood pulp.

At one time during the early commercial history of rayon, the cellulose used in its production was obtained from ordinary lint cotton, such as is used in making cotton cloth, but when the viscose method was successfully worked out (in England, about 1900) it was found that certain types of wood pulp were satisfactory 6/ and more economical than lint cotton for making rayon by this process. Several years later, cotton linters 7/ were substituted for the more expensive lint cotton for making rayon other than viscose, which was still being made from wood pulp. About 1925 or 1926, many producers of viscose rayon in the United States began using large quantities of linters pulp in mixture with wood pulp. Today, cellulose for the rayon industry in the United States is obtained entirely from cotton linters and from certain kinds of wood, the most widely used woods at present being spruce, western hemlock, and southern pine.

A number of considerations are involved in the rayon manufacturer's choice between wood pulp and cotton linters pulp, the chief ones being the physical and chemical properties of the pulp, its cost, its usable cellulose content, and the cost of processing it into rayon. But the relative importance of these factors is not the same for the different processes, and for this reason the pulps used in making rayon will be discussed under processes of manufacture.

Pulps used in viscose and cuprammonium rayon - For several years there has been a strong incentive to use wood pulp instead of linters for viscose rayon, because the price of the pulp is usually lower and more stable (table 7). Moreover, the quality of wood pulp has been improved to such a point in recent years that it is not now necessary to use linters pulp at all to make viscose rayon of standard quality. Linters pulp, however, has a usable cellulose content of about 98 percent, as compared with only about 92 percent in the grade of wood pulp generally used for viscose rayon; hence the difference in net costs to the manufacturer is not quite so great as indicated by the prices given in table 7. Despite this fact, wood pulp is usually the cheaper of the two for making rayon by the viscose process.

6/ Satisfactory for the quality of rayon then being produced.

7/ Lint cotton is composed of the long and medium-length fibers removed from the seed during the ginning process. Linters are the fibers remaining on the seed after ginning. Before the seeds are crushed to obtain oil, meal, and other cottonseed products, the linters are recovered, with varying degrees of completeness, by machinery designed especially for this purpose.

Table 7.- Approximate prices of rayon grades of cotton linters pulp and wood pulp, United States, 1929-1943

Year	Cotton linters pulp 1/	Wood pulp 2/
	Dollars per ton	Dollars per ton
1929	190	97-100
1930	165	75-95
1931	122	75-95
1932	102	70-75
1933	100	70
1934	128	70
1935	175	70
1936	162	70-72.5
1937	175	70-72.5
1938	115	85-97.5
1939	113	75-80
1940	133	75-85 3/
1941	152	85 3/
1942	163	85 3/
1943	183	85 3/

1/ F. o. b. pulp plant.
2/ Ex dock, nearest Atlantic or Gulf port. Ex dock prices for 1929, 1930, and 1931 were estimated from prices f. o. b. pulp mills.
3/ Special grades for use in making acetate rayon, etc., were quoted at $100 per ton from 1940 to July 1943, and at $110 for the remainder of 1943.

Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration. Price quotations furnished by producers of linters pulp and wood pulp, except wood pulp quotations for 1939-43, which are from the Rayon Organon.

In the earlier years, following the first use of linters pulp in the production of viscose rayon, most manufacturers held the opinion that viscose rayon of better quality could be made with a mixture of linters and wood pulp than with 100 percent wood pulp. In 1929, about 30 percent of the total pulp used in the production of viscose rayon was linters pulp, some manufacturers using a higher percentage and some a lower. By about 1932, producers of wood pulp were beginning to meet with greater success in their efforts to improve the quality of their product, and it was found possible to use increasingly higher percentages of wood pulp in the viscose process. This trend culminated a few

years later in most viscose producers using no linters at all. Linters are now used to some extent, however, and are regarded by some manufacturers as necessary in the manufacture of certain types of high-strength viscose yarns, which have increased steadily in importance since they were first introduced in 1937. According to a recent report, some manufacturers use only cotton linters in making high-strength viscose rayon; others use mixtures of linters and wood pulp, and at least one manufacturer uses wood pulp exclusively.

Shifts in the use of linters pulp and wood pulp in viscose rayon prior to 1938 are shown in the first two columns of table 8. The quantities of linters pulp used in making cuprammonium rayon 8/ are included in these figures but since cuprammonium rayon so far has constituted less than 5 percent of the total rayon produced and viscose rayon from 75 to 85 percent, the statistics illustrate satisfactorily the shift that occurred in the relative use of the two materials. Until after 1938, no wood pulp had been used for the cuprammonium process in the United States, except on a small experimental scale. Highly purified wood pulp, however, has been used for this purpose in more recent years.

Pulps used in acetate rayon - Until about 1940, only cotton linters were used in making acetate rayon in the United States. With the continued expansion of acetate rayon production, the point was reached after 1936 where this process accounted for the major part of the linters pulp used in the rayon industry. In 1929, acetate rayon took approximately one-eighth of the linters pulp consumed in all types or rayon, but by 1933 this proportion had increased to one-fourth and by 1937 to about two-thirds of the total.

Experiments aimed at the commercial utilization of wood pulp for making acetate rayon were unsuccessful for many years but eventually culminated in a highly purified grade of wood pulp having an available cellulose content nearly equal to that of linters. This type of wood pulp is now being used on a widespread scale for making acetate rayon. Although it currently sells at $25 per ton more than the grade of wood pulp generally used for viscose rayon, it is considerably lower in price than is linters pulp.

Trends in the total quantities of pulps used in making all types of rayon - Total consumption of wood pulp and linters pulp in rayon was nearly five times as great in 1943 as in 1929, and has more than doubled in the last seven years (table 8). Linters have contributed a declining percentage of this total, although the trend has not been steadily downward. In 1929, linters pulp comprised 36 percent of the total; this percentage increased to 46 percent in 1933, declined to about 25 percent during the period from 1937 to 1941, then dropped to 15 percent in 1942.

8/ Figures on consumption of pulp in the manufacture of viscose and cuprammonium rayons are grouped together because for several years there was only one domestic producer of cuprammonium rayon and any other arrangement would disclose the annual operations of this producer.

Despite its declining importance percentagewise, more linters pulp was used in 1941 than during any previous year, and consumption in 1943 was greater than during any pre-war year. In the meantime, however, consumption of wood pulp has increased tremendously and was far greater in 1942 and 1943 than in any previous year.

Present Supplies and Alternative Sources of Cellulose

With cellulose so abundant in almost all plant life, it is natural to expect that there should be a continual search for more economical sources than those now used. As an additional incentive, there is the possibility that supplies from present sources will become inadequate, either because of partial exhaustion of present supplies or because of increased demands for rayon and for products made from the same materials now used for making rayon. Furthermore, as the readily accessible supplies of wood suitable for making pulp are exhausted, the location of cutting operations will become more remote and costs will tend to rise. It is pertinent, therefore, to discuss the extent of present supplies and the potentialities of alternative sources.

Wood pulp - Taking all factors into consideration, it can be concluded almost to the point of certainty that the rayon industry will have sufficient supplies of wood pulp for many years to come. It is likely, however, that the number of species of trees from which the pulp for rayon will be obtained, and also the geographical sources of pulpwood, will be considerably extended in the future.

The type of wood pulp now used in making rayon is obtained from the same species of trees that are used in large quantities for making pulp for certain parts of the paper trade, rayon taking only a small percentage of the total amount consumed. Hence, the possibility that present supplies of wood pulp will be exhausted or become inadequate will be affected much more by the demand for certain types of paper and related products than by the demand for rayon.

There are still sufficient supplies of suitable wood to meet potential requirements for rayon type pulp for many years, and these supplies could be made to last almost indefinitely by appropriate reforestation practices. Of importance in this connection is the fact that means have been found as a result of research by which an increasing number of species of trees may be utilized for rayon pulp. At first, only spruce was considered suitable for this purpose, but after about 1927 western hemlock was used in increasing quantities, until today it is used for rayon more than any other specie. More recently, methods have been developed of using southern pine for rayon pulp, and this specie has been used commercially with success since 1939. Use of southern pine for this purpose is significant because it grows to a stage suitable for pulping much more rapidly than the other species now used.

Table 8. - Approximate quantities of wood pulp and linters pulp used in making rayon by various processes, United States, 1929-1943

Year	Viscose and Cuprammonium			Acetate	Nitro-cellulose	All processes		
	Linters pulp	Wood pulp	Total	Linters pulp	Linters pulp	Linters pulp	Wood pulp	Total
	1,000 tons	1,000 tons	1,000 tons	1,000 tons	1,000 tons	1,000 tons	1,000 tons	1,000 tons
1929	18	44	62	3	4	25	44	69
1930	20	46	66	3	3	26	46	72
1931	24	53	77	5	3	32	53	85
1932	21	44	65	6	4	31	44	75
1933	35	62	97	14	4	53	62	115
1934	34	64	98	13	2	49	64	113
1935	32	89	121	18	-	51	88	139
1936	26	104	130	21	-	47	104	151
1937	14	139	153	28	-	42	139	181
1938	1/	1/	1/	1/	-	38	110	148
1939	1/	1/	1/	1/	-	50	145	195
1940	1/	1/	1/	1/	-	60	178	238
1941	1/	1/	1/	1/	-	73	214	287
1942	1/	1/	1/	1/	-	50	280	330
1943	1/	1/	1/	1/	-	55	281	336
	Proportion of each type of pulp used							
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
1929	29	71	100	100	100	36	64	100
1930	30	70	100	100	100	36	64	100
1931	31	69	100	100	100	37	63	100
1932	32	68	100	100	100	41	59	100
1933	36	64	100	100	100	46	54	100
1934	35	65	100	100	100	44	56	100
1935	27	73	100	100	-	37	63	100
1936	20	80	100	100	-	31	69	100
1937	9	91	100	100	-	23	77	100
1938	1/	1/	1/	100	-	26	74	100
1939	1/	1/	1/	100	-	26	74	100
1940	1/	1/	1/	1/	-	25	75	100
1941	1/	1/	1/	1/	-	25	75	100
1942	1/	1/	1/	1/	-	15	85	100
1943	1/	1/	1/	1/	-	16	84	100

1/ Data not available.

The quantities shown in this table are only approximately correct. With the exception of data otherwise credited, they are based on available information for the total quantities of linters pulp and wood pulp used in chemical industries of the United States and on estimates of the quantity of each type of pulp necessary to produce 1 pound of each type of rayon. Total data for 1936 and 1938-1943 are from the Rayon Organon, March 1944, page 51.

Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration.

Still other species of trees are now technologically available as sources of cellulose for rayon. For instance, processes have been developed in the United States during the last few years that make possible the use of hardwoods, such as maple and birch, for rayon pulp. Another hardwood, beech, is reported to be used in Germany on a widespread scale, particularly for rayon staple fiber.

Linters - Whether linters will continue to be used for rayon in the future may be said to depend on two considerations: (1) Whether linters pulp will continue to possess advantages over wood pulp as a source of cellulose for certain types of rayon, and (2) the relative prices of linters pulp and wood pulp. At the present stage of rayon technology, linters pulp is regarded as having certain advantages over wood pulp as a source of cellulose for high-tenacity viscose rayon and for rayon made by the acetate and cuprammonium processes. The margin of advantage is small, however, and it is problematical whether it will continue. If, in the future, linters pulp has no technological advantage over wood pulp for use in these types of rayon, its use will depend solely upon price considerations. In the past, as indicated in table 7, linters pulp has always sold at a higher price than wood pulp.

Not only the actual price differences, but also the relative stability of the prices for linters pulp and wood pulp is an important consideration to the rayon producer. Rayon made with wood pulp has properties somewhat different from those of rayon made with cotton linters, unless there are compensating adjustments in the production processes, and these properties vary correspondingly in rayon made with different percentages of each type of pulp. Changing from one type of pulp to another thus involves some expense to the rayon producer, and it also necessitates changes in the methods of textile processors using the rayon. Since wood pulp prices are more stable than linters pulp prices (table 7), rayon producers using wood pulp would hesitate to switch to linters pulp, even if it were cheaper, unless they were certain that it would have a price advantage for a reasonable period of time.

If linters pulp were usable only in rayon and possessed no advantage over wood pulp for this purpose, its price would be expected to fall to the same level as the price of wood pulp. Linters pulp, however, is used in the manufacture of many other products besides rayon, notably smokeless powder, transparent cellulose sheeting, photographic film, lacquers and paints, plastics, and sausage casings. Linters also are normally used in large quantities for making battings, waddings, mattress felts, and other padding materials. The supply for these uses has been greatly restricted since the beginning of the war in order to provide adequate quantities for chemical purposes. Only about 20 percent of the linters consumed domestically in 1943 and during the five-year period of 1939-43 was used in rayon. From this it is clear that rayon must compete with a number of other uses for linters. Any substantial change in the demand arising from one or more of these uses can be expected to have its effect upon the price of this material and consequently its availability for rayon.

The quantity of linters produced annually is dependent, of course, on the size of the cotton crop and the efficiency with which linters are cut from the seed. Although the cotton crops produced in the United States have been relatively small since the beginning of the war, production of linters per ton of cottonseed has been considerably higher than during the pre-war years, with the result that total production of linters has been sustained at high levels (table 9). Among other factors governing the supply of linters for rayon and other uses is the relative status of exports and imports. As shown in table 9, production of linters exceeded domestic consumption and there was a substantial export balance during the crop years prior to 1940-41. More recently, this situation has been reversed and imports have exceeded exports.

Table 9.- Production, imports, exports, and consumption of cotton linters, United States, 1929-30 to 1942-43 1/

Crop year beginning August 1	Production	Imports	Exports	Consumption
	1,000 bales	1,000 bales	1,000 bales	1,000 bales
1929-30	1,038	-	118	805
1930-31	824	-	112	714
1931-32	876	-	116	637
1932-33	741	-	184	761
1933-34	801	-	169	767
1934-35	805	7	205	719
1935-36	876	45	241	734
1936-37	1,127	48	270	819
1937-38	1,471	18	275	715
1938-39	1,113	49	213	851
1939-40	1,072	63	320	1,061
1940-41	1,208	252	21	1,359
1941-42	1,184	2/	2/	1,488
1942-43	1,355	2/	2/	1,301
1943-44 3/	1,200	2/	2/	1,300

1/ In running bales averaging from 598 (1929) to 628 (1939) pounds except imports, which are in 500-pound bales.
2/ Data not available for publication.
3/ Preliminary and partly estimated.
Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration. Compiled from reports of the Bureau of the Census and the Bureau of Foreign and Domestic Commerce.

Hull fiber - After linters have been removed from the cottonseed, there is still a small amount of fuzz left attached to the seed coat or hull. In subsequent processing (after the cottonseed hulls have been cracked and the kernels separated), the hulls may be ground up by equipment installed in some cottonseed oil mills, and the fuzz or "hull fiber" separated from the "hull bran." Like linters, hull fiber is cellulose and is sometimes mixed with linters as a source of this material for certain types of rayon and other products. Because of its extremely short length and greater density, special care is required in processing it into cellulose, or heavy yield losses occur.

The price of hull fiber normally is just a little less than that of grade 6 linters. During the crop year ending in July 1944, the maximum price under government regulation for grade 6 linters in the United States was 3.50 cents per pound as compared with 3.09 cents per pound for hull fiber (70 percent alpha cellulose content). During the crop year of 1939-40, when linters prices were somewhat lower, the price of grade 6 linters averaged 2.62 cents per pound, and the price of hull fiber averaged 1.73 cents per pound.

Statistics published by the Bureau of the Census indicate an average annual production of less than 8,000 tons of hull fiber during the five years, 1939-43. In comparison, it is estimated that a potential supply of about 75,000 tons, yielding roughly 50,000 tons of alpha cellulose pulp, could be obtained from a 10-million bale cotton crop if all the hull fiber were extracted.

Failure to utilize a greater percentage of the potential supply of hull fiber is mainly due to economic considerations. In order to extract the fiber, cottonseed hulls must be ground up, and consequently they lose their value as hulls for livestock feeds and other purposes. Hence, the recovered fiber and byproducts obtained must sell for at least as much as the hulls themselves plus the cost of the processing. At present there is only a limited market for the residual ground hulls or bran, the principal outlets being in mixtures with cottonseed meal to reduce the latter to the desired protein content, in sweeping compounds, and as a source of furfural. Generally speaking, the value of hull fiber alone is not sufficiently greater than the value of the unprocessed hulls to defray the cost of processing them. Greater supplies of hull fiber can be expected to become available only if the combined value of hull fiber and hull bran is increased. This might result from new, paying uses for hull bran or from improved methods for converting hull fiber into cellulose.

Bagasse - Sugarcane bagasse 9/ provides another potential source of cellulose having characteristics similar to those of cellulose obtained from wood pulp. The Department of Agriculture, with the aid of private interests in Hawaii, has conducted experiments on a pilot-plant scale in converting bagasse into alpha cellulose. 10/ The results in Hawaii were so encouraging that the Hawaiian interests have erected a complete commercial unit at one of their sugar mills. Development of methods for obtaining alpha cellulose from bagasse has also been reported in Cuba, Japan, and elsewhere.

Potential supplies of bagasse merit some attention. From the 1942 crop of sugarcane, for instance, there was an estimated production of about 1,000,000 tons in Hawaii, 1,200,000 tons in Puerto Rico, 650,000 tons in Louisiana, and 85,000 tons in Florida. These figures indicate a total potential supply of bagasse in the neighborhood of 3,000,000 tons, about 80 percent of which, it is estimated, would have been available for converting to alpha cellulose. On a commercial scale, the pulp yield of bagasse is about 30 percent, which is lower than that of spruce and hemlock, but the pulp has an alpha cellulose content of more than 90 percent. From the 3,000,000 tons of available bagasse, therefore, about 1,000,000 tons of pulp could be obtained, a quantity vastly in excess of the total pulp requirements of the domestic rayon industry.

Although no exact figures are available on probable selling prices, there are some indications that bagasse pulp suitable for conversion into rayon could be made to sell at prices comparable to those of the usual grades of wood pulp used for rayon.

Lint cotton - Lint cotton has a high cellulose content, but certain difficulties are involved in removing impurities. Impurities in linters are easily removed, but those in lint cotton (pieces of boll and stalk, sand, etc.) can be extracted only at greater expense. It is necessary also to cut lint cotton into lengths comparable to linters in order to process it on present commercial purification equipment. Although it has been found that entirely satisfactory cellulose can be made from lint cotton, there seems to be little possibility of using lint cotton for this purpose under normal conditions. When used for this purpose, cotton would be in competition with linters and wood pulp. Cotton of even the shortest staple sells for much more than these materials, even when cotton prices are at depressed levels.

9/ Sugarcane bagasse is the cane stalk after it has been crushed and the juice extracted. A small portion of the bagasse thus produced is compressed into board form and used as a building material that has high heat- and sound-insulating properties. The remainder, which is of value only as fuel, is used mostly in the mill itself, though a small amount is sold for the same purpose in the vicinity of the mill.

10/ D. F. J. Lynch and H. J. Goss. Bagasse Cellulose. Ind. Eng. Chem. 24, 1249 (1932). Also D. F. J. Lynch. Bagasse Cellulose. Repts. Assoc. Hawaiian Sugar Tech. 13th Meeting 1934, 159-161.

Whole cotton plant - The whole cotton plant is another potential source of cellulose for the rayon industry. Alpha cellulose of a quality reported to be comparable to that of ordinary grades of commercial cellulose has been produced on a laboratory scale from the whole cotton plant. 11/ As in the case of the proposal to use short staple cotton, the greatest difficulties to be overcome seem to be economic ones, though there are chemical problems still to be solved.

Experiments carried out by the North Carolina Agricultural Experiment Station cast serious doubt on the possibility of ever growing cotton in the usual manner at a cost low enough to permit its use as a source of commercial cellulose. Cameron, 12/ therefore, proposed to disregard completely many of the characteristics of cotton that are important from a textile standpoint, such as length and uniformity of staple and maturity of the fibers, and suggested growing cotton plants to give the maximum yield of cellulose per acre, using methods that are less costly than those now followed in growing cotton for textile purposes. He proposed, also, to develop a variety that would mature early enough to permit the use of the land for other crops, thereby reducing the net cost.

Experiments carried out thus far in growing cotton plants on this basis and research to develop methods of processing them for cellulose have indicated that the proposal might be feasible. It is evident, however, that considerably more work must be done before the possibilities of this source of cellulose can be reliably evaluated.

Other potential sources of cellulose - Cereal and flax straws, soybean stems, Spanish grass (Arundo donax), bamboo, sunflower stalks, hopvines, and cornstalks are among the other materials that have been investigated in various countries as sources of cellulose for rayon. As already noted, it is chemically and physically possible to obtain cellulose suitable for commercial use from almost any kind of vegetable matter. But the mere existence of a potential source of cellulose in large quantities does not insure its suitability from an economic standpoint. Cornstalks, for instance, represent a potential source sufficiently great to supply all the present requirements for commercial cellulose in the United States, but the cost of collecting and transporting them to pulp plants, plus other ordinary costs associated with their conversion to cellulose, takes them out of the field of sources that seem likely to be competitive with wood pulp and cotton linters. Many other potential sources are uneconomical (in comparison with wood pulp and cotton linters) for the same reason.

11/ The Utilization of Whole Cotton, by Frank K. Cameron, The Cotton Trade Journal, International Edition, 1937.

12/ The Growing and Processing of Whole Cotton, by Frank K. Cameron. Proceedings of the Second Cotton Research Congress, Waco, Texas, June 26-28, 1941, p. 179.

FACTORS INFLUENCING THE USE OF RAYON

During its early history, rayon was usually thought of as competing only with silk, owing no doubt to its silklike appearance. It is now well recognized, however, that rayon also competes with cotton, wool, flax, and other textiles.

Fundamentally, rayon competes with other fibers on the basis of (1) relative price, (2) quality, and (3) style, though various important supplementary factors also have influenced its acceptance. Relative price, as a factor in competition, is most influential in connection with finished products, but it is not possible to obtain a single representative price to cover the many different forms in which the products of a textile fiber are sold at retail. However, with textiles manufactured by similar processes, relative prices of the raw fibers or of the yarns made from them usually offer a satisfactory measure of this factor. These prices are used in this section.

Quality means the physical and chemical properties of the textile material that determine such things as its adaptability to various manufacturing processes and the durability of the finished product. Style, or visual appeal, means simply the appearance of the finished product, which is of great importance in clothing, household goods, and certain other textiles. It is obvious that style is a subjective factor of competition, but it is also true that the physical and chemical properties of a textile fiber make it possible to obtain a given style effect.

It is largely through changes associated with these factors of competition (price, quality, and style) that rayon has attained its present important position in the field of textile fibers. Some of the most significant of the changes that have occurred during the past 15 or 20 years are outlined below.

Trends in the Price of Continuous Filament Rayon

Trends in the price of continuous filament rayon have been typical of the price history for most manufactured products--high in the beginning, with small production, and then a gradual decline as the quantity of rayon produced increased, manufacturing technique improved, and competition became keener. This is typified by the price history from 1911 to 1943 of 150 denier [13] viscose rayon yarn made in the United States (figure 3). There was a temporary rise during World War I, which was true of the prices of practically all commodities, followed by unusually high prices during the years immediately after the war. As raw material costs declined and the manufacturing technique improved, the price of rayon began a marked downward trend, lasting from 1920 to about 1934.

13/ The denier of a rayon yarn is a measure of its fineness (on a weight basis). It is equal to the weight in grams of 9000 meters of the yarn.

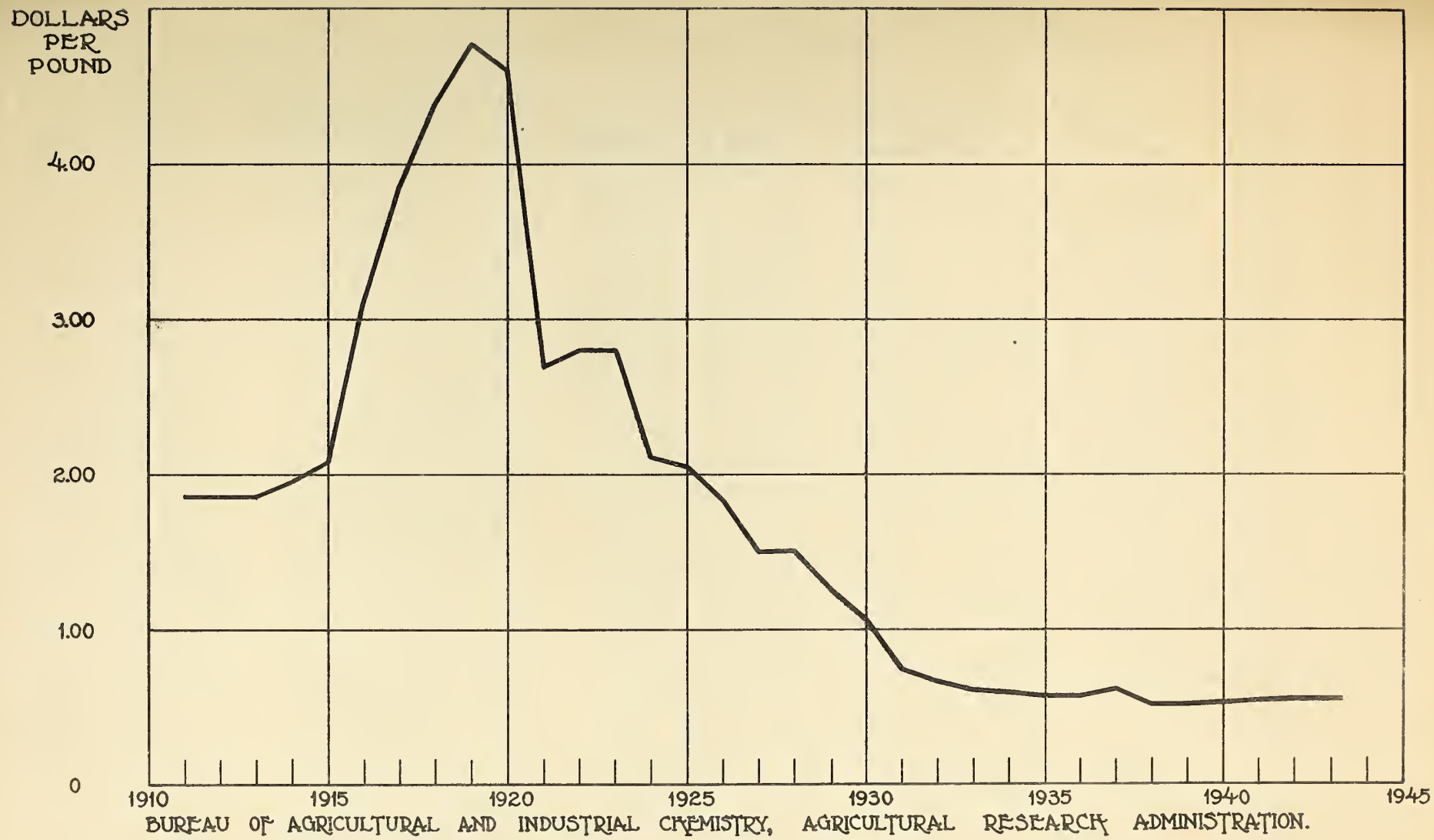


FIGURE 3. - AVERAGE YEARLY PRICE PER POUND OF 150 DENIER CONTINUOUS FILAMENT RAYON YARN[1/], 1911-1943

The price of rayon rose sharply during and immediately after World War I but has since declined and is now less than a third of the price before that period.

1/ For first quality, minimum filament, bright luster, viscose process skeins, New York, as quoted in Rayon Organon.

Since about 1934 there has been little further decline in these prices, and they have remained relatively stable thus far in the present war despite large increases in prices in general.

Corresponding rayon prices for other countries of the world are not available with sufficient completeness to make it worth while to show them. As in the United States, however, there was a decided decline in rayon prices throughout the world during the period between World War I and the present conflict.

Although prices of cotton and wool yarns also fell during the decade ending in 1932, the decline was not nearly so marked (table 10 and figure 4). Moreover, prices of wool and cotton yarns have advanced considerably since 1932, while rayon prices have declined further. Despite the fact that in many uses price is not the dominating factor in the competition of rayon with cotton and wool, the continued decline in the relative price of rayon as compared with wool and cotton unquestionably has strengthened rayon's competitive position.

The price of silk had fallen just about as rapidly and in nearly the same proportion as the price of rayon during the fifteen years preceding World War II. Although this decline may have been caused by a number of factors, it is undoubtedly true that a large part of it was directly attributable to the effectiveness of competition from rayon. To a certain extent, rayon prices acted as a kind of anchor on silk prices, that is, if the price of silk rose above a certain relative level, large quantities of silk were rapidly displaced by rayon, especially in woven goods. In 1940, however, the price of silk was still several times that of rayon.

Improvement in the Quality of Continuous Filament Rayon

The history of rayon is unique, in that its quality has been undergoing an almost continuous improvement since its introduction toward the close of the last century. Such changes are, of course, a natural consequence of its being a man-made fiber, and it is this very fact that makes the extent of its future expansion difficult to predict. Although improvements in the quality of rayon yarns have been definite, only a few of them can be measured quantitatively; hence, for certain properties, quantitative data will be given and for others simply general observations.

Strength - One of the most important properties of a textile fiber for most uses is tensile strength, and in this property rayon has undergone marked improvement during the past 25 years. The average tensile strength of 150-denier viscose-rayon yarn made by one of the large United States producers in the period 1920 to 1943 is shown in table 11. About half of all the viscose yarn produced is in the 150 denier size, and it is believed that the strengths given here are typical for most of the viscose yarns produced in large quantities.

Table 11.- Approximate tensile strength of first-quality 150-denier viscose-rayon yarn manufactured in the United States during designated years 1/

Year	Grams per denier	
	Dry	Wet
	Grams	Grams
1920	1.5	0.5
1925	1.6	0.7
1934	1.8	0.8
1937	2.0	1.0
1943	2.0	1.0

1/ Based on information supplied by a large domestic producer of viscose rayon.

Although there has been no increase in the strength of standard quality viscose yarns since 1937, special "high-tenacity" types have since become commercially important that have considerably higher strength than the strongest yarns formerly available. High-tenacity viscose rayon currently has a dry strength of about 3.6 grams per denier and a wet strength of about 2.4 grams per denier, while the "semihigh-tenacity" viscose type has corresponding strengths of approximately 3.0 and 2.0 grams per denier, respectively. Production of these types of rayon is being rapidly expanded.

Progress also has been made in increasing the strength of acetate-rayon yarns, but their tensile strength is still somewhat lower than that of comparable viscose yarns. A special type of rayon made by stretching and chemically modifying (saponifying) acetate rayon is, however, the strongest rayon manufactured, having a dry tensile strength as high as 7.0 grams per denier and a wet tensile strength as high as 6.0 grams per denier. Although unusually strong, this type of rayon elongates or stretches comparatively little before breaking. Only limited quantities have been produced thus far, and its use has been limited to military applications such as flare parachutes, shroud lines, and jungle snipers' suits.

Tensile strengths of the various types of rayon, at their present stage of development, and of certain other fibers used in textiles, are compared in table 12. As is indicated, rayon has a greater dry tensile strength than wool but is generally weaker than cotton, nylon, and better grades of silk. The saponified acetate type constitutes an exception to this rule, however, being as strong as any other textile fiber, or stronger.

Table 10. - Prices and index numbers of certain cotton, wool, silk, and rayon yarns 1/, United States, 1921-1943

Year	Average price per pound of yarn				Index numbers of average price (1923-25 = 100 percent)			
	Cotton	Wool	Silk	Rayon	Cotton	Wool	Silk	Rayon
	Dollars	Dollars	Dollars	Dollars	Percent	Percent	Percent	Percent
1921	.66	1.18	6.57	2.69	90	69	92	116
1922	.72	1.41	7.65	2,80	99	82	107	121
1923	.77	1.73	8.65	2.80	105	101	121	121
1924	.72	1.69	6.25	2.11	99	99	87	91
1925	.70	1.72	6.57	2.05	96	100	92	98
1926	.58	1.44	6.19	1.82	79	84	86	78
1927	.55	1.37	5.44	1.49	75	80	76	64
1928	.54	1.55	5.07	1.50	74	91	71	65
1929	.54	1.49	4.93	1.25	74	87	69	54
1930	.47	1.24	3.42	1.06	64	72	48	46
1931	.37	1.00	2.40	.75	51	58	34	32
1932	.31	.84	1.56	.66	42	49	22	28
1933	.41	1.08	1.61	.61	56	63	22	26
1934	.46	1.25	1.30	.59	63	73	18	25
1935	.45	1.13	1.63	.57	62	66	23	25
1936	.42	1.31	1.77	.57	58	77	25	25
1937	.44	1.38	1.86	.62	60	81	26	27
1938	.35	1.06	1.70	.52	48	62	24	22
1939	.37	1.23	2.72	.52	51	72	38	22
1940	.38	1.34	2.79	.53	52	78	39	23
1941	.49	1.64	2/	.54	67	96	2/	23
1942	.56	1.80	2/	.55	77	105	2/	24
1943	.56	1.80	2/	.55	77	105	2/	24

Note: The reader should not attach too much significance to the actual prices listed in this table. Although a careful choice has been made of the yarn to represent each fiber, other yarns in slightly different price classes might have been chosen with equal appropriateness.

1/ As follows:

Cotton, 40's single combed peeler yarn (average mid-month contract prices, New York, as quoted in Journal of Commerce).

Wool, 2/32's white, crossbred stock, worsted yarn (prices at mill as compiled by Bureau of Labor Statistics).

Silk, raw, Japan, white, 13/15 denier, 78 percent (spot prices, New York, as compiled by Bureau of Labor Statistics).

Rayon, first quality 150 denier viscose process filament yarn (prices at New York as compiled by Rayon Organon).

2/ Data not available.

Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration.

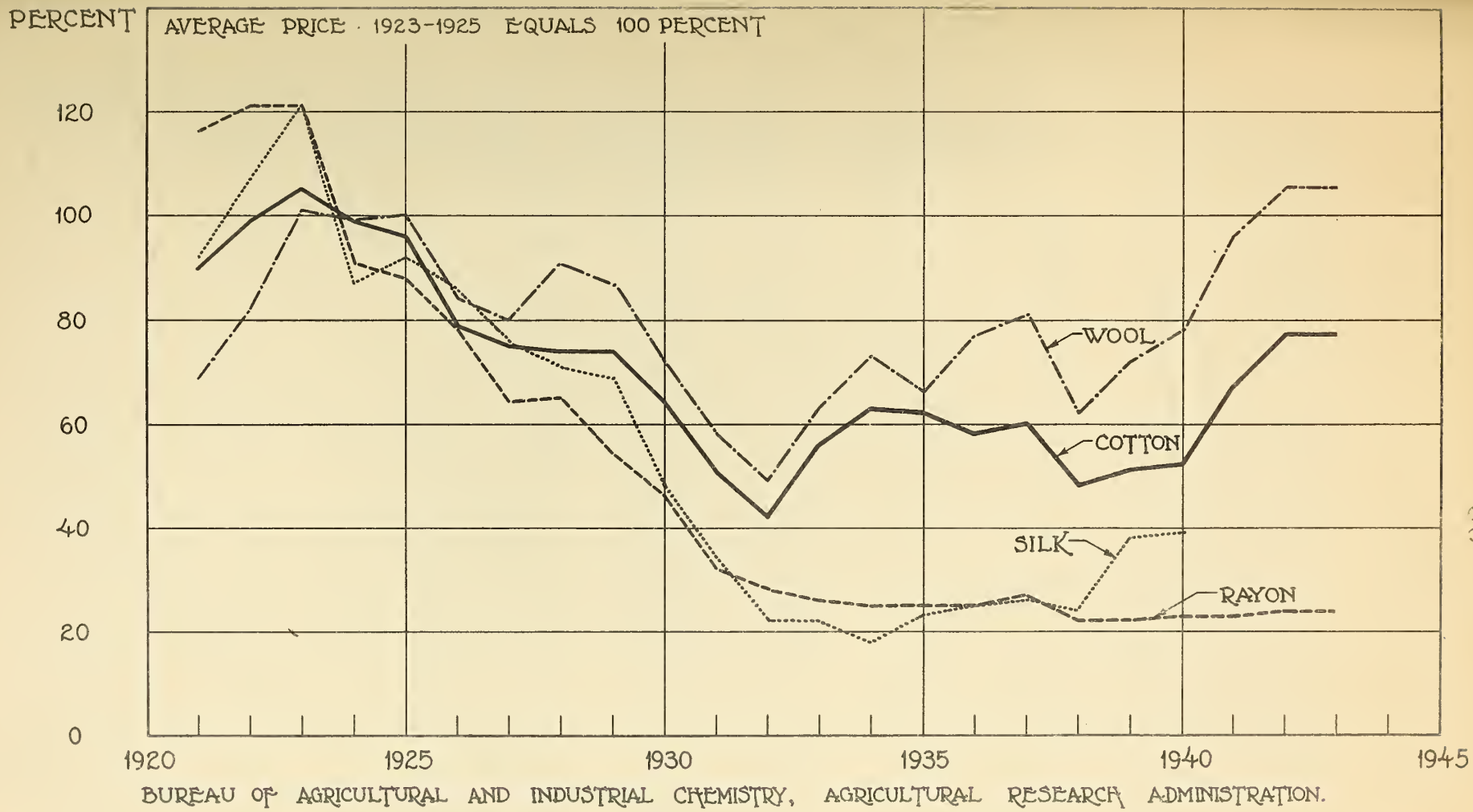


FIGURE 4. - INDEX NUMBERS OF PRICES OF CERTAIN COTTON, WOOL, SILK AND RAYON YARNS 1/, UNITED STATES, 1921-1943

During 1921-1932, prices of rayon yarn fell much further than prices of cotton and wool yarns but no more proportionately than prices of silk yarn. Although prices of cotton and wool yarn were considerably higher in 1943 than in 1932, prices of rayon yarn were somewhat lower.

1/ See table 10 for description and sources of price series used.

As is also indicated, rayon loses a greater percentage of its strength when wetted than any other fiber except casein fiber and soybean fiber. In comparison, cotton is actually stronger when wet than when dry. In comparing the tensile strengths given in table 12, it should be noted that yarns or fabrics made of continuous filament fibers, such as continuous filament rayon, generally make use of a greater percentage of the basic fiber strength shown than do yarns or fabrics made of short staple fibers, such as cotton or staple fiber rayon.

Number of filaments - The number of filaments of which a rayon yarn of any given size is composed is an important determinant of its properties. In general, the greater the number of filaments the more pliant is the yarn. Increased pliability leads to many advantages from a manufacturing standpoint, and results in a softer finished fabric with enhanced draping qualities. Furthermore, other things being equal, the greater the number of filaments the stronger will be the yarn and the fabric made from it. These and other advantages accrue from an increase in the number of filaments.

Fifteen or twenty years ago, 150-denier viscose-rayon yarns usually contained less than 20 filaments, whereas the typical 150-denier viscose yarn of today contains at least 40 filaments and frequently 90 or 100. Similar trends have occurred in acetate yarns, but yarns made by the cuprammonium process have not been appreciably altered in this respect in recent years, having always been composed of a relatively greater number of filaments. Some of the finer cuprammonium yarns are made up of the finest filaments now being manufactured commercially.

Elasticity and elongation - Low elasticity and susceptibility to permanent distortion through stretching have retarded the use of rayon where these properties are of foremost importance, such as in hosiery and some industrial uses. Published information indicates that there has been little change in either of these properties, insofar as standard grades of rayon are concerned, during the last twenty years. The various types of rayon now being manufactured vary widely in their elongation characteristics (table 12), however, making possible a much closer adaptation to the requirements of individual uses than was once the case.

Appearance - During its rise to importance as a textile fiber, rayon's silklike appearance was one of its most valuable assets in its competition with other fibers, but in uses where a glossy effect was not desirable, this characteristic was a distinct handicap. From about 1926 to 1931, several processes were developed for producing dull and semi-dull rayons. Some of the earlier processes involved the delustering of the finished yarn or fabric, but today this is usually accomplished by introducing a pigment directly into the spinning solution. The development of these various processes greatly extended the competitive field of rayon and has no doubt been one of the most important factors in its increased use.

Dyeing properties - The chemical properties of rayon are of importance mostly in connection with the dyeing process. No simple standards can be set up for comparing the dyeing properties of rayon, but they have been greatly improved during the past ten or fifteen years. Modern rayon yarns and fabrics possess greater absorptiveness and dye with more uniformity. Dyeing methods and the dyes themselves have also been improved. There are large variations in the dyeing properties of the different types of rayon, a property that has been of considerable advantage in obtaining attractive cross-dye effects in fabrics containing more than one type of rayon or rayon mixed with other fibers.

Special finishes - During the past few years, there has been an increasing amount of attention given to the treatment of textile fabrics with special finishes designed to alter their normal properties. One of the finishes most widely used with rayon consists of impregnating the fabric with some form of synthetic resin, the quantity applied ranging in weight from 1 to 15 percent on the weight of the untreated fabric. By means of such finishes, the fabric's resistance to crease may be greatly enhanced. Ability to repel water is another desirable property that may be imparted to the fabric. Some finished alter the surface appearance of the fabric and other finishes improve its color fastness. Many of these special finishes increase both the wet and the dry strength of the fabric and consequently increase the fabric's serviceability.

Uniformity - At the same time that improvements in the physical and chemical properties of rayon were being made, the uniformity of rayon in many of these properties was also being improved. Modern rayons are more uniform in their tensile strength, diameter, and denier (all of which are closely related). Likewise, improvements in the techniques of handling rayon in each of the steps of its manufacture into fabric, especially in the processes in which the material is wet, have resulted in more uniform fabrics. Improvements of this nature are advantageous in many ways. They enable the manufacturer to produce a fabric to given specifications with greater certainty and, hence, with smaller losses. Uniformity of dyeing properties, already mentioned, is obviously a desirable characteristic.

Development and Improvement of Rayon Staple Fiber

Commercial development of rayon staple fiber has been one of the most important factors in the rapidly increasing use of rayon during the last fifteen years. Because of lower manufacturing costs, resulting from the fact that it can generally be made in larger unit quantities and is less expensive to inspect and package, staple fiber is sold at a lower price by producers than the continuous filament form. Although it subsequently requires more costly processing to convert it into yarn suitable for weaving or knitting than does continuous filament rayon, it still often has an advantage in cost. It also has the advantage over continuous filament rayon of being suitable for processing on cotton and wool manu-

Table 12.- Approximate dry and wet tensile strength and elongation of synthetic fibers, and of cotton, wool, and silk

Fiber	Tensile strength		Elongation at break	
	Dry	Wet	Dry	Wet
	Grams per denier	Percent of dry		
	Grams	Percent	Percent	Percent
SYNTHETIC FIBERS:				
Rayon, viscose, regular	1.8-2.4	44-54	16-20	18-25
" , " , semihigh tenacity	2.7-2.9	62	16-20	20-27
" , " , high tenacity	3.4-3.6	61-65	9-19	14-22
Rayon, cuprammonium	1.7-2.3	55	10-17	17-33
Rayon, acetate, regular	1.2-1.6	56-68	22-30	29-38
" , saponified acetate	4.8-7.0	71-88	6	6
Nylon, regular	4.5-4.8	84-90	18-22	12-30
" , high-tenacity	6 -7.0		11-17	
Vinyon, regular	2 -2.4	100	33	33
" , "HST"	3.5-4.4	100	16	16
Vinyon E	0.2	-	400	-
Saran	1.1-1.7	100	20-30	20-30
Casein fiber	0.6	35	20-27	120
Soybean fiber	0.6	30	30	70
Glass fiber	6.5	97	2-3	1-2
NATURAL FIBERS:				
Cotton, American Upland	3.0-4.9	110-130	3-7	-
" , American Egyptian	4.2-5.5			
" , Sea Island	4.4-6.3			
Wool	1.0-1.5	80-90	30-50	-
Silk	2.8-4.7	75-85	13-20	-

Approximate values as compiled from specifications of manufacturers, published data, and laboratory tests.

facturing equipment, which comprises by far the great majority of all textile manufacturing facilities. By processing staple fiber either unmixed or mixed with other fibers on these types of machinery, it is possible to obtain entirely different types of yarns and fabrics than can be obtained by using continuous filament rayon.

Almost all the discussion dealing with improvements in the quality of continuous filament rayon (pages 30 to 35) applies to the improvements made in staple fiber since its introduction. Its strength, uniformity, and finishing and dyeing properties have all undergone changes that have increased its utility. The development of finishes that improve the crease resistance and wet strength of spun rayon fabrics has been highly important. The luster of staple fiber, of course, is controlled just as it is with continuous filament rayon. In addition, some success has been achieved in imparting a permanent crimp or waviness to this product.

Coincident with these improvements, the range of sizes, strengths, lusters, etc., in which staple fiber is available has been greatly increased, making possible improved adaptation to the requirements of specific products. This end also has been served by the introduction of special types of staple fiber for certain purposes. For instance, a type now on the market is manufactured with a pronounced crimp and with a large diameter and smooth cross-sectional outline, for use in floor coverings, upholstery, and similar fabrics where resiliency and resistance to soiling are needed. Another type, designed for use in the worsted industry, has a varied staple length to complement the fiber lengths of the wool with which it is to be blended.

Trends in the Price of Rayon Staple Fiber

Prices of viscose- and acetate-rayon staple fiber since the approximate beginning of commercial production in the United States are shown in table 13. As indicated, prices of both types of staple fiber have declined considerably since their introduction, and each change until very recently has been a reduction.

The price margin between rayon staple fiber and cotton has narrowed considerably since 1928, and in 1943 and 1944 viscose-rayon staple fiber cost less than 4 cents per pound more than middling, 15/16-inch cotton (figure 5). Viscose-rayon staple fiber has been selling for less than one-fourth the price of scoured fine territory wools since 1940.

Table 13.- Prices per pound of rayon staple fiber, 1928-1944

Viscose		Acetate	
Effective date of price change	New price 1/	Effective date of price change	New price 2/
	Cents		Cents
1928, January	60	1936, March	80
1931, October	50	" , July	60
1932, August	40	" , November	54
1934, February	34	1937, February	52
1936, June	28	1938, January	46
1937, September	25	1940, January	43
1943, May	24		
1944, March	25		

1/ For standard, bright, 1-1/2-denier, 1-1/2-inch staple. Includes freight to destination prior to September, 1941, but is f. o. b. producer's plant thereafter. Applies to all standard staple lengths and deniers after June 1936; to dull as well as bright rayon after May 1943. In June 1944, higher strength staple was priced at 1 cent more per pound than regular-strength staple; spun-dyed black and gray staple was priced at 32 cents per pound; and semidull carpet type staple sold for 29 cents per pound.

2/ For 8-denier and finer staple sizes, bright or dull, cut to any length. Premium of 2 cents per pound for 9 denier and coarser sizes. Includes freight to destination. In June 1944, spun-dyed black staple was priced at 10 cents per pound more than regular white staple.

Compiled from Rayon Organon, April 1944.

Development of Rayon Tow

Of considerable interest for its potential effect on the use of rayon in the future is the recent introduction of a new form of rayon, distinct from filament yarn or staple fiber. Rayon tow is a collection of a large number of parallel continuous rayon filaments having the general appearance of untwisted rope. It is essentially uncut staple fiber stock, in that the filaments after leaving the spinning bath are wound untwisted on paper tubes instead of being cut into staple fiber. Rayon tow is finding use in the manufacture of spun yarns by new processes in which the filaments are cut or broken into desired lengths and at the same time manipulated into spun yarn without losing their parallelism. Such methods eliminate the carding and combing operations required when staple fiber is processed on conventional cotton- or wool-manufacturing machinery, and give promise of improving the quality and reducing the cost of spun rayon yarn. Rayon tow also is being used in the manufacture of mechanical packings.

Miscellaneous Factors Affecting the Use of Rayon

Advertising - Not the least of the factors responsible for the present rapid acceptance of rayon has been an intensive advertising program. In the early days, rayon was largely used by textile manufacturers as a less expensive substitute for silk, but by means of advertising, rayon manufacturers have made the public aware of the fact that rayon is a textile distinct in its properties from all others. Such a step elevated rayon to a more dignified position, increased its appeal to the consumer, and made it possible to market rayon fabrics on their own merits rather than merely as substitutes. This resulted in a considerable widening of its field of uses.

Dissemination of information on the care of rayon fabrics - It is now commonplace knowledge that rayon fabrics require special care in cleaning and laundering, just as silk and wool do, though the care is somewhat different. There was a time, however, when the average consumer was ignorant of this fact, and articles made from rayon were more often than not damaged by improper care. As a consequence, many consumers became prejudiced against rayon. Rayon producers and manufacturers sought to prevent these injurious practices by the dissemination of information on the proper cleaning and laundering of rayon fabrics. Laundries and dry-cleaning establishments have been provided with the necessary information, so that today few rayon fabrics are mistreated in laundering and cleaning in commercial establishments through lack of knowledge of the proper methods to be followed.

Impact of War on Use of Rayon

Pre-war governmental policies - Governmental policies, such as high or low tariffs, frequently affect the relative use of various competing commodities, but only in rare instances have they had as much influence as the pre-war policies of Germany, Italy and Japan on production and consumption of rayon within their borders. Here, governmental policies were major factors in the increased use of rayon during the years immediately preceding the war. This was especially true for staple fiber. Such policies resulted partly from difficulties in obtaining adequate supplies of other textile fibers, owing to shortages of foreign exchange, and partly from an attempt to place themselves upon as self-sufficient a basis as possible. Since self-sufficiency was out of the question with cotton and was possible to only a limited extent with wool, they sought to develop and encourage synthetic fiber industries for which many of the raw materials were available within their own borders. In all three of these countries, restrictions were placed on the use of the different textile fibers in such a manner as to force, directly or indirectly, the use of larger quantities of rayon yarn and staple fiber than would otherwise have been the case.

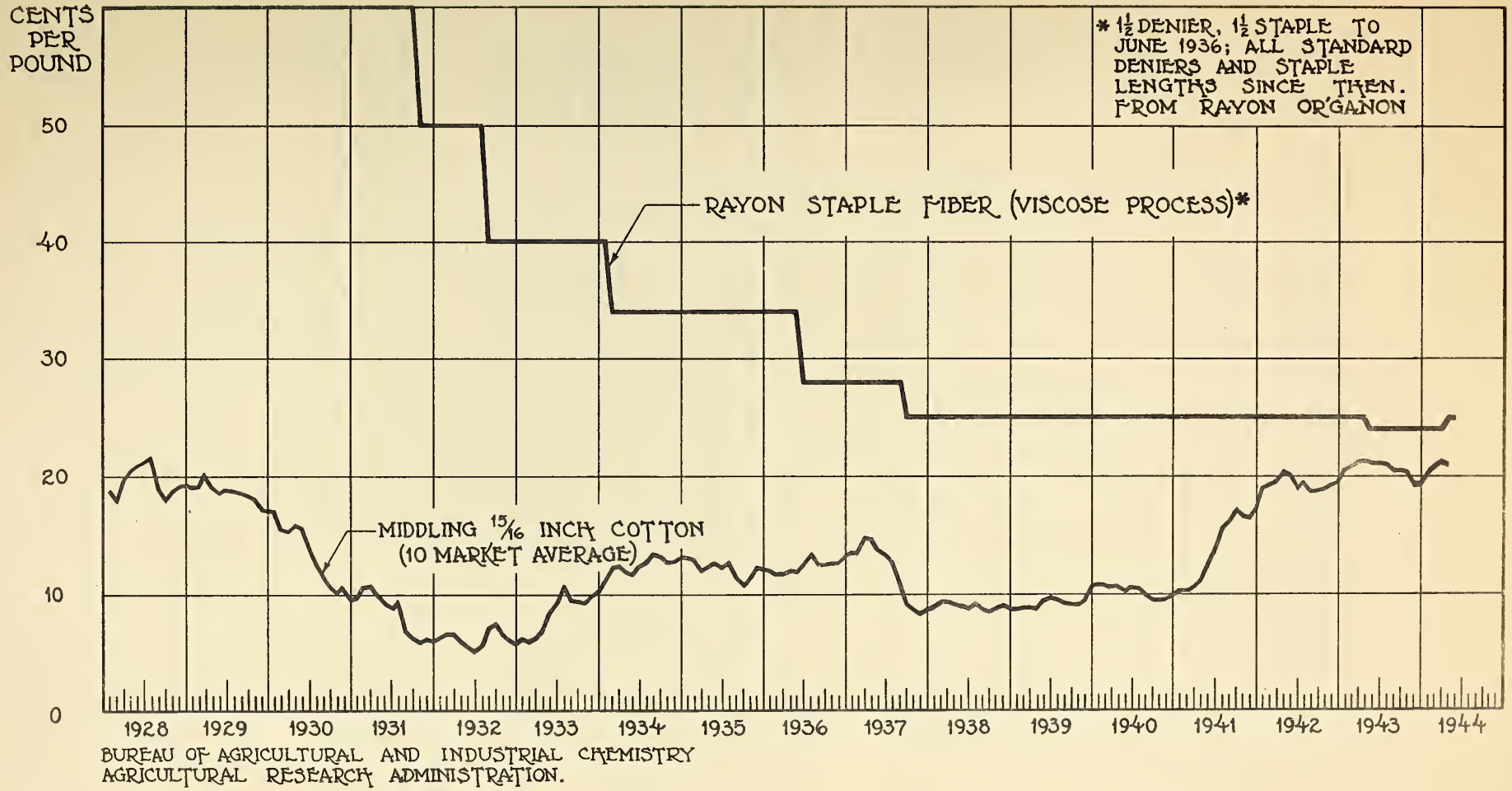

CENTS PER POUND
50
40
30
20
10
0
* 1½ DENIER, 1½ STAPLE TO JUNE 1936; ALL STANDARD DENIERS AND STAPLE LENGTHS SINCE THEN. FROM RAYON ORGANON
RAYON STAPLE FIBER (VISCOSE PROCESS)*
MIDDLING 15/16 INCH COTTON (10 MARKET AVERAGE)
1928 1929 1930 1931 1932 1933 1934 1935 1936 1937 1938 1939 1940 1941 1942 1943 1944
BUREAU OF AGRICULTURAL AND INDUSTRIAL CHEMISTRY
AGRICULTURAL RESEARCH ADMINISTRATION.

FIGURE 5. - PRICE PER POUND OF COTTON AND OF RAYON STAPLE FIBER, BY MONTHS, 1928-1944

The difference in price between rayon staple fiber and cotton was smaller in 1943 and 1944 than ever before because of several reductions since 1930 in the price of rayon staple fiber, and a marked rise in cotton prices during the present war.

Effect of war in foreign countries - With the outbreak of the war, access of Germany and Italy, and later Japan, to supplies of cotton and wool was largely restricted by blockades, making it necessary for these countries to rely more heavily than before on domestically produced rayon for their textile requirements. According to reports, production of rayon in Germany continued to increase through 1942; it also increased in France, where the domestic industry was brought into close "cooperation" with German rayon and cellulose interests. In Italy, the sea blockade made it necessary to transport needed supplies of Swedish and Finnish wood pulp for rayon over long rail routes through Germany, but production was reported to be at peak levels in 1942. In Japan, the output of rayon declined for a time after 1938, the downward trend being ascribed to deficiencies in raw materials for rayon such as wood pulp and chemicals, to a general shortage of power and coal, and to loss of export markets. More recently, it is reported to have again increased. It should be stressed, however, that little reliable information is available as to the effect of the war on rayon production and consumption in the Axis countries since the entry of the United States into the war in December 1941.

In non-Axis foreign countries, the effect of the war on the production and consumption of rayon has varied, depending on the situation of each particular country. For instance, production of rayon in Great Britain has declined below pre-war levels, reflecting this country's relatively free access to world supplies of cotton and wool and restrictions on domestic consumption of textiles caused largely by labor and shipping shortages. On the other hand, Switzerland and Sweden, cut off almost entirely from their normal sources of textile fibers, have greatly expanded their rayon production as a necessary means of meeting their textile requirements. Restrictions on international trade have also been important factors in the establishment of rayon-producing industries in Mexico and Chile, both formerly dependent on imports from Axis countries for much of their supply of rayon yarn and staple fiber.

As noted above, production and consumption of rayon yarn, particularly of rayon staple fiber, have been greatly stimulated in many foreign countries during the last few years for reasons of self-sufficiency connected with the war. This forced increase in the use of rayon has taken place in the absence of "normal" competition from cotton and other fibers, and there is thus some question as to how much of the gain will remain after a return to peace. One natural consequence of the forced use of rayon is that manufacturers have concentrated upon improving its quality and lowering its cost, which will improve the post-war competitive status of rayon throughout the world. Another consequence is that extensive rayon manufacturing facilities have been installed that, now they are in existence, will tend to remain in production. Still another consideration is that rayon can be produced in most countries at a much lower cost in terms of foreign exchange than cotton or other fibers can be imported, and therefore, if the country has a shortage of foreign exchange, rayon may be favored after the war even though the actual cost is higher.

Effect of war in the United States - In the United States, total production and consumption of rayon have increased markedly since 1939, owing at least in part to direct demands of the war program and increased civilian use engendered by it. Probably the most important effect of the war, however, has been the diversion of rayon from normal peacetime uses to uses arising directly or indirectly from the war. Such diversions have been for three purposes: (1) For direct military uses, (2) for replacement of silk and other fibers in textiles for civilian use, and (3) for export under government-sponsored programs. The quantity of rayon required for these purposes has increased steadily since the beginning of participation by the United States in the war. It is estimated that about 35 percent of the total production of rayon filament yarn and slightly less than 10 percent of the total production of staple fiber were thus accounted for during 1943.

Direct military uses of rayon include such items as parachutes, targets, linings for uniforms and sleeping bags, self-sealing gasoline tanks, flags, insignia, and most important of all, tires. Since existing facilities for producting rayon yarn were not suitable for manufacturing the high-strength viscose type demanded by the Army for tires in the quantities needed, it has been necessary for the rayon industry to undertake the conversion of a considerable proportion of its viscose-rayon facilities. Under the original conversion program announced in October 1942, provision was made for a total of 100 million pounds of high-strength rayon yarn annually, but this program was later enlarged, and new facilities were approved so that a total of 240 million pounds of this type of yarn would be available annually.

Replacement of silk and other fibers in civilian use began in August 1941, when the government required rayon producers to set aside part of their yarn production to replace silk and later nylon in hosiery and other civilian textiles for which these fibers were no longer available. Part of the production of staple fiber was similarily reserved for use by worsted manufacturers in March 1942, to relieve a shortage of wool for certain goods. Staple fiber was assured to blanket manufacturers for a similar purpose under a priority rating issued in April 1942.

As another type of diversion from normal uses, beginning in April 1942, viscose- and acetate-rayon manufacturers were required to set aside approximately 4 percent of their yarn production for export, under a government program to relieve the shortage of rayon yarn in Latin-American countries. There also was evidence, beginning in 1942, that quantities of finished rayon goods were being exported to foreign countries under the "lend-lease" program and in connection with foreign relief and rehabilitation operations.

It is difficult to predict accurately the net post-war effect of changes in production and use of rayon brought about by the war in the United States. Undoubtedly, the war has hastened the large-scale production of improved types of rayon, which will distinctly improve the competitive status of rayon in the post-war world and will open the door to uses for which rayon previously was not considered suitable. At the same time the war has hastened improvements in the applications of rayon to certain uses, such as hosiery and blended fabrics for clothing and blankets, which are likely to result in some permanent gains. Although consumers have been deprived of rayon to some extent during the war, there is at present no indication that any markets for rayon have been lost permanently thereby.

USES OF RAYON AND QUANTITIES OF RAYON AND OTHER FIBERS CONSUMED IN THE UNITED STATES

In the preceding section, an outline was given of the factors that have been instrumental in bringing rayon to its present important position in the field of textile fibers. It would be informative to follow this up by tracing the effects of competition of rayon upon each of these other fibers, but with the limited data available, it is not possible to do this accurately and completely. We may trace the consumption of rayon according to certain broad classifications, however, and gain a knowledge of its general effects.

In the past, most rayon ordinarily has gone into style fabrics, that is, into fabrics where appearance is the competitive factor of greatest importance. Such uses were found principally in the field of clothing, particularly women's clothing, and household furnishings. Until recently, only small quantities of rayon were used for industrial purposes, certain characteristics, such as its low strength, preventing any widespread use in this field. The development in the last few years of new high-strength types of rayon, however, has made possible an expansion in industrial applications, the most important of which has been for tire fabrics.

The consumption statistics on rayon to be given in this section relate to the United States only, similar data on world consumption not being available in sufficient detail to justify their inclusion.

Trends in the consumption of cotton, wool, silk, and rayon - Consumption of silk, the textile fiber first to be affected by the competition of rayon, increased on a poundage basis until 1929 but thereafter underwent a continued decline, which lasted until its withdrawal from commercial use in 1941 (table 14). Part of this decline during the years immediately after 1929 was directly attributable to a fall in the purchasing power of the country, but the failure of silk to recover its former field after 1934, in spite of its greatly reduced price (table 10), was almost wholly the result of the competition of rayon.

Trends in the consumption of wool have shown no declines that may be ascribed to the competition of rayon. As indicated in figure 6, consumption of wool maintained a fairly level trend from 1918 to 1940, if allowance is made for the depressed business years immediately following 1929, and has increased to record levels since 1940 in response to wartime military needs. Nevertheless, rayon is being used in increasing quantities for many of the same purposes as wool, in the form both of all-rayon fabrics and fabrics made of blended wool and rayon. An important factor in this competition has been the development of rayon staple fiber, since the appearance and certain other characteristics of wool fabrics can be simulated more closely with staple fiber than with continuous filament rayon. Since the quality and versatility of staple fiber are being steadily improved, further increases in the use of staple fiber in this field are not unlikely.

For many years after its original introduction, rayon was not generally considered a competitor of cotton. It is now commonly recognized, however, that a considerable part of the expansion in the consumption of rayon has been brought about at the expense of cotton. The consumption of cotton is, of course, affected by so many different factors that it is not possible to calculate with any exactness the actual poundage affected by the competition of rayon alone, but part of the downward trend (on a percentage basis), shown in table 14 and figure 6, can be attributed directly to displacement by rayon. But even though the percentage which cotton comprises of the total consumption of these competitive fibers is slightly less today than it was eight or ten years ago, cotton still has no competitor in the textile field that even approaches it in importance.

Consumption of rayon waste and recovered rayon and wool - In addition to the quantities of rayon and wool consumed (table 14) substantial quantities of spinnable rayon producers' waste and recovered rayon and wool fibers are also used in textile products. Producers' rayon waste is a byproduct of continuous filament yarn manufacture; recovered or reworked fiber is obtained from yarn and thread waste, old garments, blankets, tailor's clippings, and similar sources. It is estimated that roughly 10 million to 15 million pounds of producers' rayon waste are made available each year, most of which is used by the wool industry. The extent of use of recovered rayon and wool may be judged from census data indicating that about 12 million pounds of recovered rayon fiber and 100 million pounds of recovered wool fiber were used during 1939 in the textile industry, mostly in the wool industry. It should be borne in mind, therefore, that statistics given in table 14 underemphasize the importance of wool and rayon in comparison with cotton and silk.

Table 14. - Consumption of designated textile fibers in the United States by calendar years, 1918 to 1943

Year	Cotton 1/	Wool 2/	Rayon 3/	Silk 4/	Total	Cotton 1/	Wool 2/	Rayon 3/	Silk 4/	Total
	Million pounds	Million pounds	Million pounds	Million pounds	Million pounds	Percent	Percent	Percent	Percent	Percent
1918	2,699	399	6	49	3,153	85.6	12.6	.2	1.6	100.0
1919	2,607	329	9	56	3,001	86.9	10.9	.3	1.9	100.0
1920	2,564	314	9	40	2,927	87.6	10.7	.3	1.4	100.0
1921	2,383	343	20	52	2,797	85.2	12.3	.7	1.8	100.0
1922	2,639	406	25	58	3,128	84.4	13.0	.8	1.8	100.0
1923	2,850	422	33	62	3,367	84.7	12.5	1.0	1.8	100.0
1924	2,399	342	42	61	2,844	84.4	12.0	1.5	2.1	100.0
1925	2,800	350	58	77	3,285	85.2	10.7	1.8	2.3	100.0
1926	2,909	345	61	78	3,391	85.8	10.1	1.8	2.3	100.0
1927	3,262	354	100	86	3,802	85.8	9.3	2.6	2.3	100.0
1928	2,901	333	100	88	3,422	84.8	9.7	2.9	2.6	100.0
1929	3,105	368	133	98	3,704	83.8	9.9	3.6	2.7	100.0
1930	2,383	263	119	82	2,847	83.7	9.2	4.2	2.9	100.0
1931	2,398	311	159	89	2,957	81.1	10.5	5.4	3.0	100.0
1932	2,245	230	155	78	2,708	82.9	8.5	5.7	2.9	100.0
1933	2,769	317	217	73	3,376	82.0	9.4	6.4	2.2	100.0
1934	2,430	230	197	60	2,917	83.3	7.9	6.7	2.1	100.0
1935	2,504	418	259	72	3,253	77.0	12.8	8.0	2.2	100.0
1936	3,154	406	322	68	3,950	79.8	10.3	8.2	1.7	100.0
1937	3,300	381	305	64	4,050	81.5	9.4	7.5	1.6	100.0
1938	2,668	284	329	57	3,338	79.9	8.5	9.9	1.7	100.0
1939	3,299	396	459	55	4,209	78.4	9.4	10.9	1.3	100.0
1940	3,612	407	482	48	4,549	79.4	8.9	10.6	1.1	100.0
1941	4,709	648	592	24 5/	5,973	78.8	10.9	9.9	0.4	100.0
1942	5,109	604	621	6/	6,334	80.7	9.5	9.8	-	100.0
1943	4,863	636	656	6/	6,155	79.0	10.3	10.7	-	100.0

1/ From the reports of the Bureau of the Census. American cotton was converted to pounds from running bales on the basis of the average net weight of bales produced in the preceding crop year; foreign cotton was converted from 500-pound bales, 3 percent being deducted for tare. Linters are not included. An allowance of 9 percent has been made for waste removed in the manufacturing process.

2/ From Bureau of the Census reports. Carpet and apparel class, scoured.

3/ From the Rayon Organon of the Textile Economics Bureau. Calculated as the sum of domestic shipments by producers plus yarn imported for consumption, plus staple fiber available for consumption. Does not include rayon waste.

4/ Imports as given in Foreign Commerce and Navigation of the United States. Total of raw silk and silk waste.

5/ Imported for consumption. January-September only.

6/ Data not available but probably nominal.

Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration.

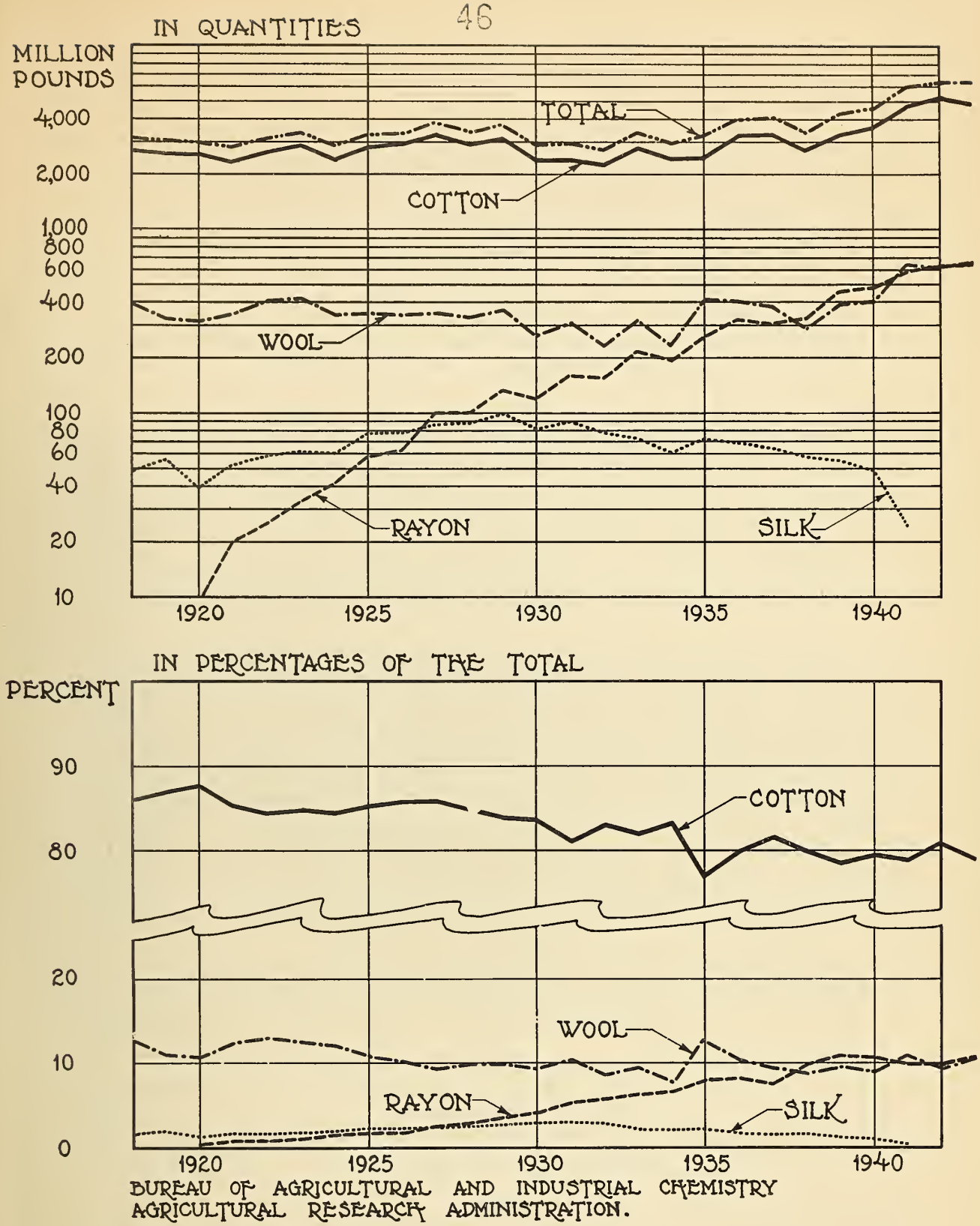


FIGURE 6. - CONSUMPTION OF DESIGNATED TEXTILE FIBERS IN THE UNITED STATES, 1918-1943

Rayon consumption has increased more rapidly than consumption of any other fiber during the last 25 years and now accounts for about 10 percent of the total consumption of cotton, wool, silk and rayon. Although consumption of cotton was at record levels in 1943, it was less important, percentagewise, than during the years before 1935. (See table 14 for sources.)

Consumption of continuous filament rayon by trades - From 1912 to 1922, the greater part of the rayon produced went to the knit-goods trade, where most of it, up to 1920, was used in hosiery (table 15). Beginning about 1923 and continuing through 1930, shipments of filament rayon were about evenly divided between the knit-goods and the woven-goods industries, knit goods other than hosiery (underwear, dresses, sweaters, ties, etc.) taking by far the greater part of the rayon going into knit goods. In the woven-goods industry, broad goods took larger and larger quantities, whereas narrow goods showed no appreciable increase on a poundage basis and actually declined on a percentage basis.

The period from 1930 to 1943 is of unusual interest. During these years the production and consumption of continuous filament rayon increased more than fourfold. One outstanding feature of this increase in the use of filament rayon is that it occurred mostly in the woven-goods industry, that is, the tremendous increase since 1930--more than 300 million pounds--is almost entirely accounted for by its expanded use in woven goods. In contrast, consumption of rayon yarn in knit goods increased only 51 million pounds, of which 33 million pounds represented a wartime increase since 1940 in hosiery (figure 7).

Consumption of rayon staple fiber - Consumption of staple fiber by uses has not been discussed separately, but the rapid increase in its consumption during the last few years makes it deserving of special attention. Many people close to the textile field believe that rayon's greatest expansion in the future will come about through expansion in the use of staple fiber. Before 1928, practically no staple fiber was used in this country. Even as late as 1934, it showed no marked signs of becoming of much importance, but thereafter expansion was rapid. The consumption of staple fiber in 1935 amounted to only slightly more than 2 percent of the total domestic consumption of rayon, but by 1937 it had increased to nearly 12 percent (table 16) and by 1943 to nearly 25 percent.

Statistics showing quantitative trends in individual uses are not available, but some of the classes of uses in which staple fiber is employed will be enumerated and briefly discussed.

Little use has yet been made of staple fiber in knit goods, except small quantities for such purposes as women's knit outerwear and underwear, men's hose, and women's knit gloves. Staple fiber comprises only a small percentage of the total fiber used for these purposes, and less than 3 percent of the staple fiber consumed is used for knitting.

By far the most important use at present for staple fiber is in woven goods, both alone and in mixture with one of the natural fibers such as cotton or wool. Because it can be produced in any desired length, it can be converted into yarn on all types of cotton- and wool-spinning machinery. Most of it, however, is processed on cotton machinery.

Novel and attractive effects in clothing and household articles have been obtained by mixing staple fiber with cotton, wool, linen, and other fibers. The cross-dye effects resulting from such mixtures, especially those with wool, are particularly attractive. Many new fabrics have been developed in this manner, and these have been responsible in a large measure for the success that staple fiber has had in the textile field.

Woven fabrics made of staple fiber have found their principal use thus far in women's and men's outerwear. One group of fabrics is made of staple fiber mixed with wool to simulate woolen and worsted fabrics such as flannels, tweeds, and twills, for use in men's and women's suits and in men's slacks. In such applications staple fiber may serve to lower the cost of the final product or to extend supplies of wool, if this is needed. Another group of fabrics in which staple fiber is used, including poplins, gabardines, and failles, either all rayon or mixed with cotton, is used widely in slack suits and sport shirts. Staple fiber also finds a large market in women's dress goods, such as linen-like and challislike fabrics, and washable shantungs.

In non-apparel uses, staple fiber is used to a considerable extent in tablecloths, napkins, draperies, upholstering fabrics, etc. It also has had increased use since the beginning of the war in wool mixtures for blankets and carpets. Utilization of staple fiber is still in an active stage of development with new uses appearing from time to time as improvements are made in its physical characteristics and adaptability. As the use of staple fiber increases, it will exert its influence in fabric fields other than those mentioned above, and the competitive picture may be considerably changed.

Relative Consumption of Rayon and Other Fibers in Specific Uses

Woven goods other than tire fabrics - Woven goods, excluding tire fabrics, now take approximately three-fourths of the domestic output of continuous filament rayon, [14] most of the increase having taken place within the last ten years. Accurate statistics are not available with sufficient completeness to trace the effects of competition of rayon upon the consumption of other textile fibers in woven goods, but its general effects are fairly well known. Silk has been directly and heavily affected, as indicated by estimates that consumption of silk in uses other than hosiery declined from 59 million pounds in 1929 to 9 million pounds in 1939. Had it not been for the increased use of silk in hosiery, the decline in the total consumption of silk, prior to its withdrawal from use in 1941, would have been much more drastic. Cotton and wool have also been replaced by rayon, cotton probably being much more affected than wool.

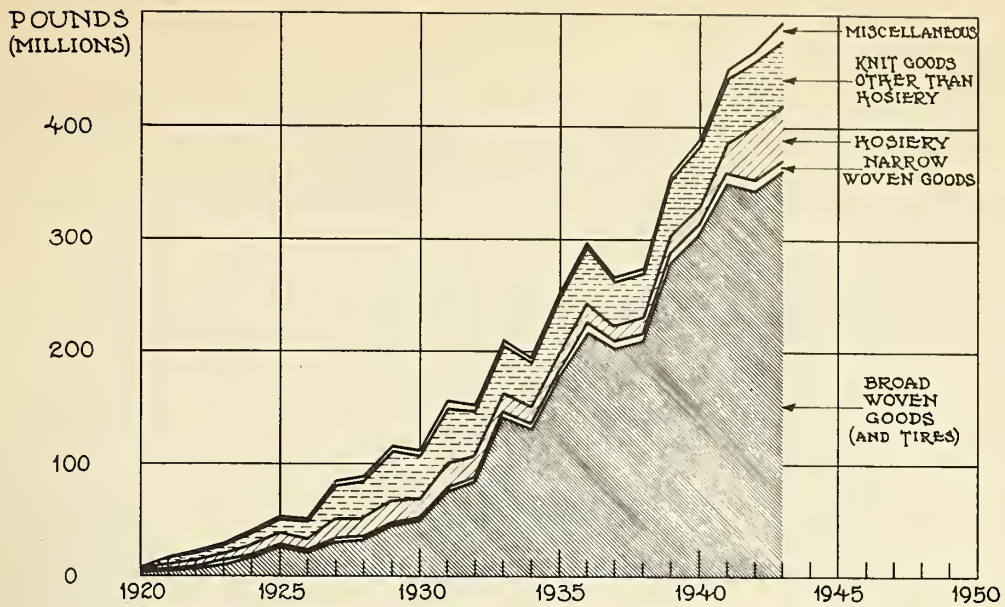
14/ Although no precise data are available on the distribution of rayon staple fiber by trades, most of it is known to go into woven goods, so for continuous filament and staple fiber combined, the proportion going into woven goods would be even higher than three-fourths.

Table 15. - Distribution of domestic continuous filament rayon shipments by trades 1/
United States, 1912 to 1943

Year	Knit Goods						Woven Goods						Miscellaneous 6/		Total Shipments
	Hosiery 2/		Other Knit 3/		Total Knit		Broad Woven and Tires 4/		Narrow Woven 5/		Total Woven				
	Million Pounds	7/ Percent	Million Pounds	7/ Percent	Million Pounds	7/ Percent	Million Pounds	7/ Percent	Million Pounds	7/ Percent	Million Pounds	7/ Percent	Million Pounds	7/ Percent	Million Pounds
1912	0.4	36	-	-	0.4	36	0.6	55	0.1	9	0.7	64	-	-	1.1
1913	0.8	50	-	-	0.8	50	0.8	50	-	-	0.8	50	-	-	1.6
1914	1.2	50	-	-	1.2	50	1.2	50	-	-	1.2	50	-	-	2.4
1915	2.7	66	0.2	5	2.9	71	1.2	29	-	-	1.2	29	-	-	4.1
1916	3.8	67	0.5	9	4.3	76	1.3	23	0.1	1	1.4	24	-	-	5.7
1917	4.1	64	0.3	5	4.4	69	1.9	30	0.1	1	2.0	31	-	-	6.4
1918	3.5	60	0.3	5	3.8	65	1.7	30	0.3	5	2.0	35	-	-	5.8
1919	3.1	39	1.2	14	4.3	53	2.7	33	1.2	14	3.9	47	-	-	8.2
1920	2.0	28	1.7	24	3.7	52	2.3	32	1.2	16	3.4	48	-	-	7.1
1921	4.1	25	5.6	34	9.7	59	4.1	25	2.6	16	6.7	41	-	-	16.4
1922	5.8	26	7.2	33	13.0	59	5.8	26	3.0	13	8.8	39	0.7	2	22.5
1923	6.8	23	8.3	28	15.1	51	10.2	35	3.6	12	13.8	47	0.5	2	29.4
1924	8.6	21	11.3	28	19.9	49	16.0	40	2.8	7	18.8	47	1.5	4	40.2
1925	10.7	20	10.5	20	21.2	40	26.1	50	2.9	5	29.0	55	2.6	5	52.8
1926	10.3	20	15.0	29	25.3	49	21.2	42	2.2	4	23.4	46	2.6	5	51.3
1927	16.7	20	28.9	34	45.6	54	31.5	37	3.3	4	34.8	41	4.6	5	85.0
1928	14.7	17	32.9	37	47.6	54	32.5	37	3.2	4	35.7	41	4.7	5	88.0
1929	18.8	16	43.7	37	62.5	53	45.4	39	3.1	3	48.5	42	5.4	5	116.4
1930	16.5	15	38.0	34	54.5	49	49.5	44	3.0	3	52.5	47	4.6	4	111.6
1931	21.1	14	48.7	31	69.8	45	75.6	49	4.0	2	79.6	51	6.2	4	155.6
1932	19.0	13	38.0	25	57.0	38	84.6	56	3.9	2	88.5	58	6.3	4	151.8
1933	17.0	8	41.3	20	58.3	28	141.3	67	5.5	2	146.8	69	5.9	3	211.0
1934	14.1	7	39.9	21	54.0	28	131.3	68	4.8	2	136.1	70	4.6	2	194.7
1935	14.7	6	47.9	19	62.6	25	179.5	71	5.2	2	184.7	73	5.4	2	252.7
1936	16.3	5	51.0	17	67.3	22	217.0	73	8.2	3	225.2	76	4.9	2	297.4
1937	12.6	5	38.9	15	51.5	19	202.5	75	7.4	3	209.9	79	4.8	2	266.2
1938	14.1	5	39.6	14	53.7	20	209.3	76	6.7	2	216.0	79	4.1	1	273.8
1939	16.2	4	49.9	14	66.1	18	278.6	77	9.1	3	287.7	80	5.8	2	359.6
1940	16.4	4	54.0	14	70.4	18	304.4	78	8.2	2	312.6	80	5.7	2	388.7
1941	26.3	6	57.9	13	84.2	19	349.2	77	10.2	2	359.4	79	8.8	2	452.4
1942	49.3	11	56.3	12	105.6	23	343.6	73	8.7	2	352.3	75	10.9	2	468.8
1943	49.2	10	56.1	11	105.3	21	360.4	73	10.4	2	370.8	75	18.1	4	494.2

1/ Viscose, oupra, and nitro yarn 1912 to 1924. Includes acetate yarn 1925 to date.
2/ "Hosiery" includes all manufacturers of seamless and full-fashioned hosiery.
3/ "Other knit" includes all manufacturers of circular and flat-knit underwear plus other knit goods such as outerwear, sweaters, neckties, and knitted dress goods.
4/ "Broad woven" includes all broad-loom weavers whether they be "silk weavers", "cotton weavers", "woolen and worsted weavers" or rayon weavers.
5/ "Narrow woven" includes manufacturers of such items as ribbons, tapes, and woven elastic goods. which are of a width narrower than 18 inches.
6/ "Miscellaneous" includes all other outlets such as bag, lace, and braid manufacturers.
7/ Percent of total shipments.

Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration. Compiled from Rayon Organon of the Textile Economics Bureau, Vol. XV, No. 2, "Special Supplement 1943 Annual Rayon and Textile Statistics", and earlier issues.



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COMPILED FROM RAYON ORGANON.

FIGURE 7. - DISTRIBUTION OF DOMESTIC CONTINUOUS FILAMENT RAYON BY TRADES, UNITED STATES, 1920-1943

Since 1930, consumption of filament rayon in woven goods has increased nearly sevenfold; in knit goods it has only doubled.

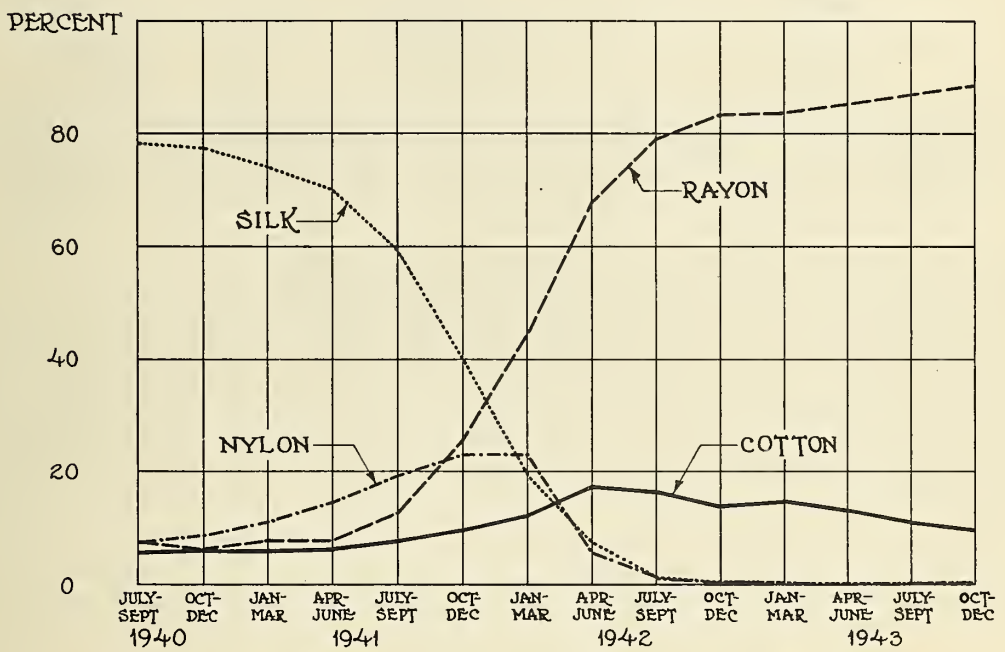

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FIGURE 8. - SHIFTS IN PERCENTAGES OF WOMEN'S FULL-LENGTH HOSIERY MADE OF VARIOUS FIBERS, UNITED STATES, 1940-1943

Production of women's rayon hosiery (full-fashioned and seamless) increased rapidly after withdrawal of silk in August 1941 and nylon in February 1942.

Table 16.- Estimated consumption of rayon staple fiber, United States, 1928-1943

Year	Quantity	Percentage of total rayon consumption
	1,000 pounds	Percent
1928	365	0.4
1929	1,936	1.5
1930	868	0.7
1931	1,595	1.0
1932	3,296	2.1
1933	5,420	2.5
1934	2,111	1.1
1935	6,347	2.4
1936	24,828	7.7
1937	37,641	12.4
1938	55,328	16.8
1939	98,963	21.6
1940	93,316	19.4
1941	139,327	23.5
1942	151,806	24.5
1943	161,863	24.7

Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration. Quantities are from the Rayon Organon.

Much of the competition between rayon and silk has been on the basis of price, and hence rayon's gain is likely to be permanent, since it is highly unlikely that silk will ever be cheaper than rayon. On the other hand, much of the competition between rayon and cotton and between rayon and wool has been on the basis of fabric style characteristics. For instance, rayon gained in the dress field at the expense of cotton not because of lower prices but because of effective competition in appearance, draping qualities, and other style characteristics. However, the fact that prices of cotton and wool have risen markedly since the beginning of the war while prices of rayon have remained relatively stationary undoubtedly has been an important factor in the competition between these fibers.

Hosiery - Price, style, and serviceability are competitive factors that vary greatly in importance in determining relative quantities of the various textile fibers used in different types of hosiery. For example, in women's hosiery, appearance outweighs a considerable difference in price, and beyond a certain required minimum, serviceability without satisfactory appearance is of little

importance. In men's hosiery, price, appearance, and durability are of more nearly equal importance, while in children's hose, durability and price are of more importance than in either men's or women's hosiery.

In women's hosiery, there have been extreme shifts in the relative use of textile fibers. In 1919 more than half of the women's hosiery produced was all cotton, but since then cotton has steadily declined in importance until less than 10 percent was all cotton during the years immediately preceding the war. Silk hosiery, on the contrary, increased from 39 percent of the total production in 1919 to 84 percent in 1937 and 1939 (table 17). Commercial introduction of women's nylon hosiery in May 1940 was followed by a rapid increase in their use, and by the first quarter of 1941 this type comprised 10 percent of the total production of women's full-length hosiery, including both full-fashioned and seamless (table 18).

Production of women's rayon hose (mostly made with cotton tops, heels, and toes) increased steadily from 2 percent of the total in 1919 to 18 percent in 1929, but then declined to less than 10 percent during the years immediately preceding the war. A tendency toward use of sheer hosiery, for which rayon was not so suitable as silk, has been a major factor in the trend since 1929. Steadily declining silk prices was another reason why rayon hosiery failed to make further gains after 1929.

With the coming of the present war, however, rayon again gained rapidly in importance, largely because of the lack of silk and nylon. A government order prohibiting the use of silk for nondefense purposes in August 1941 made necessary increased use of nylon, rayon, and cotton, but nylon hosiery, after increasing to 23 percent of the total production of women's full-length hosiery at the close of 1941, was also withdrawn from civilian use in February 1942. In the meantime, rayon hosiery steadily increased in importance as the best available substitute for silk and nylon, and at the close of 1942 comprised more than 80 percent of all women's full-length hosiery manufactured. Use of cotton hosiery also has increased somewhat, but this type of hosiery comprised only 10 percent of the total at the end of 1943 (table 18, figure 8).

Although considerable progress has been made since 1941 in adapting rayon to women's hosiery, the great majority of consumers still regard rayon as definitely inferior to both nylon and silk for this purpose. Still further improvement in women's rayon hosiery can be expected when high-tenacity rayon becomes available for this purpose, but undoubtedly most of this market will return to nylon and silk when the war is over.

Table 17. - Hosiery production by fiber content in the United States during designated years, 1919-1939 [1]

Type	Million dozen pairs				Percentage of totals			
	1919	1929	1937	1939	1919	1929	1937	1939
Total, all types	84.6	117.3	123.6	149.6	100.0	100.0	100.0	100.0
All cotton	60.6	35.2	38.4	53.0	71.6	30.0	31.1	35.4
Rayon (including mixtures with cotton) [2]	1.6	34.4	30.3	33.1	1.9	29.3	24.5	22.1
Silk and silk mixtures [2]	17.2	38.4	48.2	54.8	20.3	32.8	39.0	36.6
Wool (including mixtures with cotton and rayon)	5.2	5.4	4.3	1.6 [3]	6.2	4.6	3.5	1.1 [3]
Other mixtures, etc.	-	3.9	2.4	7.1 [3]	-	3.3	1.9	4.8 [3]
Total, women's	30.7	51.2	53.6	63.8	100.0	100.0	100.0	100.0
All cotton	17.7	7.3	3.9	5.5	57.6	14.2	7.3	8.6
Rayon (including mixtures with cotton) [2]	.7	9.3	3.4	3.9	2.3	18.2	6.3	6.1
Silk and silk mixtures [2]	12.0	33.5	45.2	53.6	39.1	65.4	84.3	84.0
Wool (including mixtures with cotton and rayon)	.3	.6	[4]	[4]	1.0	1.2	[4]	[4]
Other mixtures, etc.	-	.5	1.1	.8	-	1.0	2.1	1.3
Total, men's, children's, etc. [5]	53.9	66.1	70.1	85.8	100.0	100.0	100.0	100.0
All cotton	42.9	27.9	34.5	47.5	79.6	42.2	49.3	55.4
Rayon (including mixtures with cotton) [2]	.9	25.1	26.9	29.2	1.7	38.0	38.4	34.0
Silk and silk mixtures [2]	5.2	4.9	3.0	1.2	9.6	7.4	4.3	1.4
Wool (including mixtures with cotton and rayon)	4.9	4.8	4.3	1.6 [3]	9.1	7.3	6.1	1.9 [3]
Other mixtures, etc.	-	3.4	1.3	6.3 [3]	-	5.1	1.9	7.3 [3]

[1] Does not include athletic and golf hose.
[2] Includes hosiery with cotton tops, heels, and toes. Silk and rayon mixtures are included under silk; wool and rayon mixtures are under wool.
[3] Cotton-wool mixed men's seamless included under "other."
[4] Less than 50,000 dozen pairs, or 0.05 percent.
[5] Men's, boys', misses', children's, infants'.

Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration.
Compiled from Census of Manufactures.

Table 18.- Production of women's full-length hosiery, by fiber content, in the United States during designated periods, 1940-1943 1/

Period	Total		Silk	Nylon	Rayon 2/	Cotton 2/	Other 2/
	Mil.doz pairs	Percent	Percent	Percent	Percent	Percent	Percent
1940,							
Jan.-June	26.6	100.0	80.8	2.8	9.0	6.2	1.2
July-Sept.	13.2	100.0	78.3	7.2	7.6	5.8	1.1
Oct.-Dec.	15.0	100.0	77.5	8.7	6.4	6.3	1.1
1941,							
Jan.-March	14.5	100.0	74.1	10.9	7.9	6.2	.9
April-June	15.0	100.0	70.2	14.5	7.9	6.4	1.0
July-Sept.	12.6	100.0	59.3	19.3	12.7	7.8	.9
Oct.-Dec.	12.8	100.0	40.2	22.9	25.8	9.9	1.2
1942,							
Jan.-March	11.8	100.0	19.1	22.9	44.1	12.4	1.5
April-June	12.0	100.0	7.6	5.6	67.9	17.5	1.4
July-Sept.	12.3	100.0	1.3	1.3	79.1	16.7	1.6
Oct.-Dec.	12.2	100.0	.5	.4	83.6	14.1	1.4
1943,							
Jan.-March	12.6	100.0	.2	.1	83.7	14.7	1.3
April-June	12.4	100.0	.1	3/	85.3	13.2	1.4
July-Sept.	12.1	100.0	.1	3/	87.2	11.0	1.7
Oct.-Dec.	12.6	100.0	.1	3/	88.8	9.6	1.5

1/ Compiled from estimates of National Association of Hosiery Manufacturers based on more than 80 percent coverage of the industry. Includes both full-fashioned and seamless full-length hosiery. Does not include ribbed hose.

2/ A small quantity of full-fashioned cotton and rayon hosiery is included under "other" from January 1940, through October 1941.

3/ Less than 0.05 percent.

Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration.

Half hose, principally men's, accounted for most of the rayon used in hosiery prior to World War II, but there had been only small increases in the use of rayon for this purpose after 1929. Cotton was the fiber most affected by competition of rayon in this use, but it staged a comeback after 1929, production of all-cotton hosiery for men and children increasing from 42 percent of the total in 1929 to 55 percent in 1939 (table 17). This increase was due in considerable part to the popularization of sport hosiery made primarily of cotton, such as anklets and slack and crew socks.

Knit goods other than hosiery - No published figures are available showing the relative consumption of the various textile fibers in knit goods other than hosiery, including principally knit underwear and outerwear. Cotton is by far the most important fiber used in these goods as a group, but rayon and wool are important competitors. As already noted, consumption of rayon in knit goods other than hosiery has increased slowly during the last few years (table 15).

Tire fabrics - Until just recently, rayon has been used almost entirely for wearing apparel and household textiles in applications where style and appearance are of primary importance. Relatively little use was made of rayon in other important classes of textiles in which strength and durability are highly important. Marked improvements during the last few years in rayon's properties have now made it possible to consider rayon for some applications of this type, however, and one such use, tire fabric, recently has developed into one of the most important uses of rayon.

Although experimental rayon tire fabrics were made as far back as 1924, rayon tires were not placed on the market until 1937, following the development of a suitable adhesive for bonding rubber to rayon and of a satisfactory high-strength rayon. Expansion in the new field was slow at first, and by 1939 only about 7 million pounds of rayon yarn were being used for this purpose, as compared with approximately 288 million pounds of cotton cord and fabric. Use of rayon at this time was limited almost entirely to high-speed, heavy-duty, truck and bus tires, where its superior durability under extra heavy service conditions, as compared with cotton fabrics then used, were considered to outweigh its higher price.

With the coming of war, the expansion of rayon into the tire fabric field was given a tremendous impetus by the decision of government authorities to specify the use of high-tenacity rayon in tires for certain classes of military and civilian vehicles and aircraft. There has been considerable controversy regarding this decision and the factors leading to it. According to available information, it was based on the belief that rayon tires would give superior service under the conditions for which they were to be used and that less rubber would be required in making them. It was claimed, in this connection, that rayon tire fabrics were lighter and stronger than cotton fabrics and that they maintained their strength better under high temperatures. The latter was said to be important because more heat than usual is generated in military tires because of their extreme thickness. Also, tires made of synthetic rubber generate more heat than those made of natural rubber.

Following this decision, a program was set up by the War Production Board to greatly increase the production of high-tenacity rayon. As already mentioned, manufacturing facilities are at present (1944) being converted and added under this program, so that a total of 240 million

pounds of high-tenacity viscose-rayon yarn will be produced annually, by far most of which is to be used in tires. It is not expected, however, that the output will approach a rate sufficient to meet this goal until the latter part of 1944.

Whether rayon will permanently displace cotton in tires is a matter of vital importance to cotton growers and processors, since tires have constituted the largest single use of cotton, requiring an average of approximately 600 thousand bales per year during the years 1935-39. No definite answer can be given to this question because several highly uncertain factors are involved. Although it generally is agreed that rayon tire fabric is superior to old types of cotton tire fabrics, there is considerable controversy as to whether it is better for the various classes of service than the improved types of cotton fabrics that have been and are now being developed. Much will depend, of course, on the relative prices of cotton and rayon fabrics after the war ans whether the difference is sufficient to outweigh any technical advantage of one over the other in any or all types of tires. The fact that rayon will be firmly entrenched in the field, with facilities and techniques already established, is important.

TEXTILE PRODUCTS NOT GENERALLY MADE OF RAYON

As the quality of rayon has been improved, the number of products in which it is used has increased. There are still certain classes of textiles, however, for which rayon, with its present properties and its present price, is not so suited as other fibers. Owing to certain of its properties, there is an actual but not sharply defined limit to the extent to which rayon in its present stage of development can displace cotton and wool. Of course, as has been noted, rayon is a man-made fiber, and its various properties have by no means been permanently fixed, but nevertheless some of its present limitations can be pointed out.

The expansion of rayon until recently has been largely into those fields where style and appearance are of paramount importance. There are many textile uses, however, where the appearance of the article is a minor consideration. Most industrial applications fall in this class, and until the recent development of rayon tire fabrics, little rayon found a market in this field. Then there are many uses where durability combined with low price is required. Many articles of clothing and household furnishings, as well as certain industrial products, are of this type. Some of the more important of these will be briefly discussed.

Bags - One of the most important single uses of cotton in the United States is for various types of bags. In some peacetime years, nearly 500,000 bales go into the manufacture of bags, and considerably larger quantities of cotton have been required for this purpose since the beginning of the war. In addition to cotton, the materials most widely used for making bags are jute and paper. Both these materials, and the grades and staples of cotton used, are low priced, so low priced, in fact, that even if bags made from rayon could meet all the physical requirements for this purpose, it is unlikely that they would be employed because of their comparatively high cost.

Work clothing - Another large and highly important use of cotton is for work clothing, consisting principally of various kinds of overalls, work shirts, and work pants. In 1939, for instance, some 500,000 odd bales of medium- and short-staple cotton went into the manufacture of men's, youths', and boys' garments of these types. For a use such as this, fabrics should possess considerable strength and launderability and be low in price. Cotton fabrics meet all these requirements so well that they have had practically no competition with fabrics made of other fibers. Rayon fabrics, in particular, are not so durable for such purposes and generally cannot be made to sell at so low a price. Therefore, any considerable use of rayon in this field is unlikely, at least in the near future. Some use has been made of rayon, however, in certain types of women's work clothing.

Men's business and dress shirts - Many attempts have been made to produce a rayon fabric that would enter the men's business and dress shirt trade, but so far they have met with little permanent success. Around 200,000 bales of cotton are consumed each for this purpose, making the incentive for these attempts obvious. Rayon shirts are higher priced than the cotton shirts that sell in greatest volume. In addition to this difference in price and the fact that cotton shirts are much more durable, present habits and customs give almost every advantage to the cotton shirt. There is associated with the newly starched cotton shirt a refreshing sense of cleanliness that has not been duplicated with any other type of fabric. Even silk shirts, in which there was a moderate volume of trade in the years following the first World War, did not have an appeal equal to that of the much less costly cotton shirt.

Rayon shirts now make up a small part of the trade in men's business and dress shirts, but since cotton shirts furnish satisfactory service at a lower cost, the bulk of this field has been practically closed to rayon. It should not be overlooked, however, that rayon is extensively used in sport shirts and that this type of shirt has been displacing the business or dress shirt to some extent in American custom.

Men's and boys' underwear - Although rayon is used to a limited extent for men's and boys' underwear, most underwear of this type is made of cotton, more than 200,000 bales of cotton going into this use annually. Cotton, of course, enjoys the advantage of custom in this field, but it also has superior wearing qualities and stands up better under the frequent launderings to which men's and boys' underwear is subjected. Cotton underwear is also generally lower in price than rayon underwear, although there are exceptions to this rule.

Sheets and pillowcases - With the exception of a minor proportion made from linen, practically all sheets and pillowcases are made from cotton. Moderate strength and the ability to withstand frequent laundering with little wear and tear are the principal requirements of the fabrics that go into this use, though there are, of course, additional requirements.

To displace cotton in sheets and pillowcases to any appreciable extent, another textile fiber would have to be within the price range of cotton. Linen sheets and pillowcases, though more durable than those made from cotton, do not occupy a large part of this field because of their comparatively high cost. Some sheets and pillowcases made from rayon have been placed on the market, but partly because of their higher price and partly because they are not so durable, they have not replaced any measurable quantities of cotton, nor are they likely to, under these conditions, though their use may conceivably be extended somewhat in that part of this field which might be classed as "guest linens."

Towels - Some part-rayon towels are now being produced, but the chance that rayon will take over a substantial part of this field is negligible. Cotton towels are durable, have excellent absorptive properties, can be produced in attractive designs, and are cheaper than those made of rayon, linen, or any combination of two or more of these three fibers. Of the 200,000 to 250,000 bales of cotton going into this use each year, only negligible quantities are in danger of being replaced by rayon.

Men's wool suitings - Rayon staple fiber and rayon waste have been mixed with wool for use in men's woolen and worsted suits and topcoats for several years, but only small quantities were involved before the war. In this application, rayon waste and staple fiber have been used mainly as adulterants to keep the price of suitings down, and the resulting mixtures have been confined almost entirely to the lower-priced suits. Use of staple fiber in suits of this type increased somewhat after the beginning of the war, owing to a wartime shortage of wool for civilian use.

Although continued efforts have been made to extend the use of rayon to medium and higher priced wool suits and topcoats, these efforts have generally been unsuccessful. Fine wools make a fabric that retains its shape throughout its useful life, a property not obtainable in fabrics made with a mixture of wool and either cotton or rayon. These mixed fiber fabrics may and often do possess a greater tensile strength, as tested on ordinary tensile-strength machines, but all-wool suitings possess sufficient strength for their use, and resiliency is of much greater importance. In addition, all-wool suitings possess better wearing qualities and greater resistance to moisture, and withstand ordinary cleaning processes better than wool-rayon blends. Until a rayon staple fiber with a higher degree of permanent resiliency and with increased durability and wet strength is developed, its penetration into the field of men's medium and higher priced wool suitings will be negligible, even with the price of staple fiber less than that of wool.

Cordage and twine - From 400 to 600 million pounds of cordage and twine are manufactured annually in the United States from the various hard fibers and from cotton, jute, flax, and hemp. No rayon has been used in this field, with the exception of negligible quantities in decorative cords. Since strength and durability at very low cost are usually demanded of the fibers used for cordage and twine, it is unlikely that rayon will be used to any great extent for this purpose.

Other uses - Rayon has had little or no use in such diverse products as awnings, tents, sails, tarpaulins, slip covers, bookbindings, artificial leather, bandages, gauze and dressings, felt goods, men's and boys' hats and caps, and diapers, to mention a few. These uses illustrate certain advantages of cotton, silk, wool and other fibers over rayon in such properties as strength, durability, resistance to heat, felting qualities, and others, either with or without advantages in cost.

General observations - As already mentioned, most rayon is used in apparel and household goods where style and appearance are prime objectives. In such uses, it may have displaced silk or wool because of its lower price, or it may have displaced cotton because its advantages outweighed its higher price. The recent development of high-tenacity rayon, however, has made possible the expansion of rayon into another group of uses, including heavy-duty truck and bus tires, airplane tires, and parachutes, where rayon is used, though higher in price, because it affords a higher strength-to-weight ratio than can be had in cotton products now available. Since this development is recent, it may be expected that there will be some further expansion in this field. On the other hand, rayon has made little progress, thus far, into uses where strength and durability are demanded at a low price or where it has other specific disadvantages, such as those mentioned in the preceding paragraphs.

OTHER SYNTHETIC FIBERS

The development of rayon has been so outstanding that it is easy to overlook the existence and importance of other synthetic fibers. Although new synthetic fibers have been announced from time to time, only a few have reached the stage of commercial production, and none were on the market until about 1935. Among the synthetic fibers now in commercial production in the United States are nylon, Vinyon, Vinyon E, saran, casein fiber, and glass fiber. In addition, a fiber made of soybean protein has been produced on a pilot-plant scale, although there has been no true commercial production as yet. Each of these synthetic fibers has certain distinctive properties that merit attention, and some have increased rapidly in importance.

NYLON

Although nylon fiber has been in commercial production less than five years, it now is used in the United States in larger quantities than any other synthetic fiber except rayon. The announcement of the development of nylon in 1938 marked the successful commercial application of research undertaken ten years earlier for the purpose of developing fundamental information regarding certain chemical materials and processes. This research was carried out in the laboratories of one of the large chemical companies.

Strictly speaking, the term "nylon" is properly applied not to a fiber but to a group of new chemical compounds known as synthetic polyamides, which may be made into sheets, bristles, molded plastics, coatings for fabrics and wires, and other products, as well as, most importantly, textile fibers. It is theoretically possible to make thousands of types of nylon. Thus far, ten different types, each with distinctive properties, have been placed in commercial production. The first type to be developed, however, the so-called fiber 66, is still the type used most widely for textile purposes. The following comments apply to this type only, unless otherwise stated.

In the manufacture of this type of nylon, the principal base materials used are benzene or phenol (carbolic acid), both commonly derived from bituminous coal; ammonia, which may be synthesized from air and water; and oxygen. Other types, however, may be derived from other raw materials, including vegetable oils. The manufacturing process involves a series of chemical operations, from the last of which nylon emerges from an autoclave in the form of a molten ribbon. On cooling, this ribbon is cut into small chips and stored until needed for forming into fiber or other products. If nylon fiber is to be made, the chips are melted, and the molten liquid is pumped through the tiny holes of a spinnerette. As soon as the resulting filaments strike the air outside the spinnerette, they solidify. They are later cold drawn to four or more times their original length, this process serving to impart strength and elasticity.

Nylon fiber has gained widespread acceptance in textiles because it possesses unusually excellent properties in many respects. For instance, its usual dry tensile strength of from 4.5 to 7.0 grams per denier is considerably higher even than that of the high-strength types of rayon used in tire cords and makes possible stronger yarns than have been made of any natural fiber. Unlike rayon, it loses little of its strength when wet, its usual wet strength averaging about 90 percent of the dry strength. In another important physical property, elasticity, it is reported to surpass all the natural fibers and rayon, a factor of major importance in such uses as hosiery and fishing lines.

Nylon has the unusual characteristic of taking a substantially permanent set or shape when heated with hot water or saturated steam, a property of value in the manufacture of hosiery. It is thermoplastic, but its melting temperature of about 480° F. is considerably higher than that of other thermoplastic fibers used in textiles. Chemically, it is highly resistant to alkalies and is unaffected by ordinary dry cleaning solvents, although it is degraded by mineral acids. It can be dyed with a wider range of dyestuffs than other common fibers, but the dyes used for acetate rayon give the best results for most purposes. Nylon is resistant to mildew and marine and soil micro-organisms but can be damaged by moths and ants, which will cut their way through nylon fabrics if imprisoned.

Nylon has certain properties that give it an advantage in some uses but place it at a disadvantage in others. It absorbs much less moisture than other commonly used fibers, a property that would be advantageous in raincoats but a disadvantage in a product such as towels. This characteristic makes it possible to wash and dry nylon stockings more quickly than silk and rayon stockings, but has been a factor in the complaint that they sometimes feel clammy and that rain or perspiration makes them slippery. Another disadvantage is nylon's attribute of easily becoming charged with static electricity, which has caused trouble in processing it. On the other hand, its electrical qualities have led to the use of nylon in the form of both yarns and coatings for insulating wires. Nylon fabrics will deteriorate from exposure to sunlight at the same or a greater rate than cotton or rayon but less rapidly than silk.

Although production of nylon has increased rapidly since it was first announced in 1938, lack of productive capacity has prevented its use, thus far, in all but a limited number of textile applications. Nylon was produced on a pilot-plant scale only until the close of 1939, when the first commercial plant was completed and the output was increased to about 4 million pounds per year. Thereafter, manufacturing facilities were successively expanded until by 1942 the capacity was large enough to provide about 20 million pounds per year. Further expansion of nylon capacity for the post-war period is definitely planned.

Prior to the war, nylon had entered only one important textile use on a large scale, namely, women's hosiery. Its success in this field is well known and already has been mentioned (page 51). In addition, nylon yarn was used on a small scale in a variety of other products, such as neckties, fishlines, thread, foundation garments, women's knitted and woven underwear, and sheer fabrics for women's outerwear. Although it was meeting with success in these fields, production was insufficient to meet the needs for these uses or to supply many other potential uses.

With the coming of war, use of nylon for civilian purposes was stopped, and the entire production was devoted to wartime needs. Probably the most important of its military applications has been for parachutes, where it has served to replace silk. It also is being used for such purposes as towlines to pull gliders, climbing ropes for mountain troops, and shoelaces to resist deterioration in the tropics. In addition, nylon has recently been used on a limited scale in large airplane tires, after experiments which were reported to have shown that it was superior to both rayon and cotton for this purpose. In nearly all these and other applications, nylon has been used in the form of filament yarn, although nylon staple fiber has been developed and used to a limited extent for some purposes.

Considering only its physical characteristics, it would not be difficult to forecast a future for nylon in which it occupied as important a place in the textile field as does rayon today. The cost at which it can be made available must be considered, however, for no matter how excellent a fiber's properties, its use would be seriously limited if the cost were too high. When nylon was first made available for hosiery in 1940, it was priced at $4.27 to $4.55 per pound in yarn sizes suitable for hosiery, prices that were competitive at that time with the best grades of silk. Since then, prices have been reduced several times, and in March 1944, certain sizes commonly used for military purposes (not comparable with hosiery yarns mentioned above) ranged in price from $1.62 to $2.65 per pound, depending on the size and put-up.

Although prices of nylon yarn still are considerably higher than the prices of cotton, wool, or rayon, further price reductions are reported to be likely as the volume of production increases. It is considered unlikely, however, that nylon will ever be as low in price as rayon, since the materials involved are more costly.

It is difficult to forecast at this time the probable effect of nylon on consumption of cotton and other fibers. Thus far, nylon has been used largely to replace silk in products such as stockings, parachutes, thread, and fishlines, where the competitive fibers had little or no price advantage. To replace cotton, wool, or rayon in a given use it would have to possess advantages sufficient, in the estimation

of the consumer, to outweigh its higher cost. Little information is available on this point, since nylon, thus far, has gone into only a limited number of uses. Considering its properties and its price, however, it seems entirely conservative to predict that nylon will be used in the next few years in at least as large volume as was silk in the years preceding the war.

VINYON

In addition to nylon, other fibers made of synthetic resins have made their bid for a place in textile markets during the last few years. Included in this group are Vinyon, Vinyon E, and saran. Vinyon is made from a special grade of vinyl resin, a plastic material also used in safety glass, suspenders, watch crystals, and other products. Technically, it is a copolymerization product of vinyl chloride and vinyl acetate, which in turn are derived from air, coal, water, natural gas, and salt. In its manufacture, the vinyl resin in powder form is dissolved in acetone, and the resulting "dope" is forced through spinnerettes into hot air, where the acetone evaporates. The process is much the same as that for making acetate rayon, except that higher air pressures and temperatures are used. The resulting vinyon filaments are then stretched to increase tensile strength and reduce extensibility, after which they are twisted and wound on cones or tubes or cut into staple fiber.

Thus far, Vinyon has had its most important use in industrial filter cloths, where its unusual resistance to acids, alkalies, and other liquids and gases is important. It also has been used to a limited extent in fish nets and fishlines, where its resistance to water is an advantage, and in gloves, upholstery, millinery cloth, and other textiles. Vinyon has the decided disadvantage of shrinking at a temperature of 150° F., which precludes its use in garments and other textiles that are ironed at ordinary temperatures. This property, however, is utilized in the manufacture of felts, where Vinyon cements together nonfelting fibers, such as cotton, jute, or asbestos. In dry tensile strength, Vinyon compares favorably with even the types of rayon used for tire cord and, unlike rayon, loses none of its strength when wet. It is reported to have excellent elasticity.

Vinyon was introduced commercially in 1939. It currently sells for $1.40 to $1.80 per pound in continuous filament form, depending on the yarn size and put-up, and for $1.00 or $1.15 per pound in the form of coarse or fine staple fiber. Considering its properties and price, it may be concluded that, although Vinyon serves excellently for certain specific purposes, it offers no advantage over other fibers for the great majority of textile uses.

VINYON E

Recently a fiber of the same general type as Vinyon has been introduced that is reported to have a much higher elasticity than any other textile fiber. This fiber, known as Vinyon E, is made from the same materials as ordinary Vinyon, except that a special plasticizer is added to the spinning "dope" before it is forced through the spinnerettes. Yarns made of Vinyon E are reported to stretch from 150 to 300 percent of their length but will not snap back as fast as rubber or latex yarns. Use of Vinyon E is limited at present to military purposes. In this field it has served, thus far, to replace rubber in such products as elastic tapes for military clothing and suspension cords for jungle hammocks.

SARAN

Saran is a name applied to vinylidene chloride resins, derived from petroleum and brine, that recently have been introduced in continuous filament form for use in textiles. Like Vinyon, saran is thermoplastic, but its melting temperature is considerably higher, ranging (in the form now used for textiles) from 240° to 280° F. Saran also resembles Vinyon in having high resistance to acids and common alkalies, and in being practically waterproof.

Fibers for textile use are made by melting saran, forcing it through suitable dies into a cold-water bath, and cold-drawing the resulting filaments to increase their strength. Saran fibers have been made only in comparatively coarse sizes so far, and, although they are tough and have marked resistance to rupture from flexing, their dry tensile strength does not exceed that of ordinary viscose rayon.

Production of saran fiber is limited, the quantity being used for weaving purposes totaling only about one million pounds per year, at present, all of which goes into screening. In addition, saran filaments are being used at present in cordage for certain applications and have been made into fabrics for upholstering seats on buses, trains, etc. and for other purposes.

Like Vinyon, it may be concluded that saran fiber with its present properties offers no advantage over other fibers in the great majority of textile uses, although it is useful for certain specific purposes.

CASEIN FIBER

Considerable research work has been performed in this country and elsewhere in recent years with the object of developing synthetic fibers from natural protein materials, such as casein, soybeans, corn, peanuts, and fish. Research of this type is of more than usual interest

to the farmer, since it may lead to new markets for certain farm crops. As a result of this work, one new fiber, casein fiber, has already reached the commercial stage in the United States, and another, soybean fiber, has been produced experimentally on a pilot-plant scale. Only these two fibers will be discussed in this report, since there is little as yet to indicate that commercially practicable fibers can be made from other natural protein materials.

The first casein fiber to be produced on a commercial scale was developed in Italy and was placed on the market in the spring of 1936. This fiber, named "Lanital," was reported to be the result of research directed specifically toward the development of a synthetic wool. By 1938, Italian production of "Lanital" had increased to 3.7 million pounds per year, and by the beginning of the war, patent rights had been purchased by several other European countries, some of which were producing casein fiber on a limited scale. Little reliable information is available as to progress in production and utilization of this type of fiber in Europe since the beginning of the war.

In the United States, the Bureau of Dairy Industry of the United States Department of Agriculture developed a process for making a casein-base textile fiber and was issued public patents in December 1938, and thereafter. Developmental work with the same object in view was also carried out by private industry, culminating in the commercial introduction of a casein fiber named "Aralac" in about 1940. Production of this fiber since has increased to a current rate of about 8 million pounds per year (1943).

Casein is the principal raw material used in the manufacture of "Lanital" and "Aralac," about one pound of casein being required per pound of fiber. The source of casein is skimmed milk, which yields about 3 percent of its weight in this material. In the production of "Aralac," thoroughly blended casein is dispersed in water by means of alkali, forming a thick siruplike solution, which is forced through spinnerettes into a coagulating bath in much the same manner as is done in making rayon. The filaments thus formed are then subjected to a number of chemical treatments interspersed with washings and dryings, which impart desired properties, such as softness, flexibility, and resistance to hot water. As a last step, the fiber is cut into the desired staple length and baled.

"Aralac" is commercially available at present in staple lengths ranging from one-half to six inches and in finenesses comparable to 50s, 60s, and 70s wool. It can be had either with or without a woollike crimp. "Aralac" currently sells for 64 cents per pound, which is considerably below the prices that have prevailed for clothing wools since the beginning of the war.

Chemically, casein fiber is fairly similar to wool and can be dyed with the same kind of dyes and like wool it is readily damaged by alkalies. It also is comparable with wool in its appearance, warmth qualities, and ability to absorb moisture without feeling damp and clammy. On the other hand, it is less elastic and not so crease-resistant as wool, and the surface structure is such that it possesses less clinging power. Casein fiber has a somewhat lower dry strength than wool, and its wet strength is so decidedly inferior as to constitute probably the fiber's most important disadvantage.

Up to the present, casein fiber has been used almost entirely for blending with rayon, cotton, wool, and fur. As such it imparts certain woollike characteristics to fabrics containing rayon or cotton or serves as a cheaper substitute for wool or fur. The largest use of casein fiber in the textile field has been in dress fabrics, but it also has been used in such articles as coats, men's suits and underwear, blankets, neckties, scarfs, and socks. In addition, it is blended with fur and wool for use in felt hats. Casein fiber has been used without blending in this country only as a filling for cushions, pillows, etc., and in linings.

It is difficult to forecast the future of casein fiber for textile purposes, since it has been used for only a short time in limited quantities, and little information is available regarding its value for various purposes. Because of its nature, probably its chief use will be in the type of textiles now made of wool. As yet, however, fabrics made entirely of casein fibers have not been regarded as suited for the great majority of textile uses because of deficiencies in wearing qualities and certain other properties. It, therefore, has generally been necessary to mix this fiber with others for textile purposes. It is not unlikely, of course, that the future will bring improvements in the properties of casein fiber that will change this situation, thereby increasing its potentialities as a competitor in the textile field.

SOYBEAN FIBER

Research work to develop a fiber derived from soybeans has been carried out by several different groups in the United States and in foreign countries. In the United States, efforts of one group have reached the stage where soybean fiber is being produced on a pilot-plant scale. Thus far, there has been no true commercial production of this fiber in this country.

Soybean fiber, as developed in the United States, is generally similar to casein fiber in its properties and potential uses. It is reported to be somewhat comparable with wool in its resiliency, heat-insulating characteristics, and reaction to dyes, but its dry tensile strength is below that of wool, and its wet strength is so low as to constitute a major obstacle to its commercial use.

Soybean fiber is made from soybean protein, a derivative of soybean meal, which is obtained when soybeans are processed to extract the oil. It is reported that about 20 pounds of soybean protein can be produced from 100 pounds of soybeans and that about one pound of protein is required per pound of fiber. It is planned currently to sell soybean fiber at about 65 cents per pound.

GLASS FIBER

The fact that glass when raised to a high temperature can be drawn out into long filaments has been known for centuries, and many of the physical properties of such filaments have also been known, but not until a few years ago was any persistant effort made to produce a glass fiber in a form suitable for textile uses. In Germany during the first World War, when it was impossible to secure adequate supplies of asbestos, a method was evolved for the mass production of glass fibers for use in making sound- and heat-insulating materials. Essentially, the method consisted in passing molten glass through a number of small orifices, from which it was pulled onto a winding device. The bundle of filaments thus obtained was then processed into various types of sound- and heat-insulating materials. Modifications of this method are still in commercial use today.

Beginning in 1931, attention in the United States was directed toward means of producing glass filaments of increasingly smaller diameters that would be suitable for use in textiles and other products. These efforts led a few years later to commercial introduction of glass fiber for textiles in two forms--continuous filament and cut staple. Both forms are produced by attenuating the molten glass as it issues from orifices in glass furnaces. Attenuation of the staple fiber is accomplished by high-pressure jets of steam or air, whereas the continuous filament type is drawn out by a high-speed winding mechanism.

Textiles from glass fiber have properties sufficiently different from those made of cotton, silk, wool, or rayon to merit attention. Outstanding among their desirable properties is the ability to withstand high temperatures with little or no damage. Also, being made of glass, they are unaffected by many of the chemicals that are highly injurious to other textiles and are not subject to attack from micro-organisms causing mildew and other forms of deterioration.

On the other hand, glass textiles in their present state of development possess certain undesirable properties which limit their field of potential use. Although they possess an unusually high tensile strength, they lack resiliency and ability to stretch. Glass-fiber yarns have an extensibility of only about 1 or 2 percent (in comparison with 15 to 20 percent for ordinary textiles), and the fabrics made from them are correspondingly deficient in this property. Also, in spite of

their extreme fineness, glass-fiber yarns are more brittle and less flexible than those made from ordinary textile fibers, and glass-fiber fabrics are not soft to the touch and lack durability when they are subjected to a great deal of bending. They definitely are not suitable for clothing.

Because of these properties, glass-fiber textiles have proved to be suitable for only a rather definite and restricted field of uses, but in the uses for which they are adaptable they seem to possess decided advantages. For instance, glass-fiber filter cloths and anode bags for electroplating are valuable in certain chemical industries. Tapes and yarns of glass fiber are used to a limited extent to insulate motors, transformers, and other types of electrical apparatus. A novel wartime use has been in parachute flare shades. Potential expansion in the use of glass fibers would seem to be greatest in fields where a fireproof fabric is desirable, for instance, in awnings, screens, lamp shades, and curtains. Glass-fiber textiles, however, are still in such an early stage of development that it is unsafe to hazard a guess as to the uses for which they may eventually be found suitable.

POST-WAR OUTLOOK FOR SYNTHETIC FIBERS

As indicated in the preceding pages, marked progress has been made in the development of synthetic fibers generally during the last few years, and at the same time use of these fibers has been rapidly expanding. How long these trends will continue and what bearing they will have on future markets for cotton and wool are questions that are of vital importance to producers and processors of these fibers and of considerable interest to the public generally. These questions cannot be answered definitely, for obvious reasons, but consideration can be given to some of the factors that are likely to be important in arriving at the answers.

Over a period of years, expansion in the use of synthetic fibers is dependent to a considerable degree upon continuing technological progress in the development of these fibers. Using the past and present as a guide to the future, it can be noted that several of the most important improvements in the history of rayon have been made within the last few years, and there is every indication that this progress is continuing at present. As for the other synthetic fibers, it might be said that they are yet in their infancy, chronologically speaking. Until a few years ago rayon was the only synthetic fiber used commercially, but since then new fibers have appeared from time to time, some of which excel all others in certain characteristics. Other fibers, now in the experimental stage, may be expected to be placed on the market in the post-war period. Although some of the new fibers may be failures and some may find only limited use, others undoubtedly will find important

places in the textile field. Considering the amount of research being devoted at present to the development and improvement of new synthetic fibers and the general rate of scientific progress, it may be safely concluded that the rate of technological progress in synthetic fibers generally will be at least as great in the future as it has been in the past.

Another factor determining the outlook for synthetic fibers is the price at which they will be available. In the last few years, prices of some of the synthetic fibers have declined while others have remained stationary in the face of a rising general price level. There is evidence that post-war reductions in price are possible, but whether prices will actually be lowered will depend upon the profitability of the new markets to be gained by such a step. With the newer synthetic fibers, at least, further price reductions may be expected, because they are new products, and economies effected by mass production and from improved technology as such products are developed, are normally reflected in lowered prices.

In the past, technological progress accompanied by a downward trend in prices, has resulted in a marked upward trend in production and consumption of synthetic fibers. On the basis of conclusions in the foregoing discussion that these tendencies are likely to persist, it can be expected that production and use of synthetic fibers will continue to increase, although actual year-to-year increases cannot be predicted with accuracy. Much will depend, of course, upon business conditions and upon the intensity of competition from other fibers.

What implications do these tendencies have for producers, as well as processors and consumers, of cotton and wool? Despite the rapid increase in the consumption of rayon and other synthetic fibers during the last few years, domestic consumption of cotton and wool has recently been at an all-time high. This undoubtedly is due at least in large part, however, to the unprecedented wartime demand for textiles of all sorts rather than to any fundamental shift in the competitive relationships between fibers. There is no question but that synthetic fibers have displaced both wool and cotton in certain uses during the last few years, and undoubtedly consumption of both would have been greater if rayon had not been available. In the future as in the past, much of any expansion in the use of synthetic fibers can be expected to be at the expense of already existing fibers, but part can be expected to represent a net gain for textiles in general.

The extent to which synthetic fibers will eventually displace cotton and wool is difficult to predict. For one thing, it is unlikely at any foreseeable time that cotton and wool will be completely displaced by synthetics. Even if synthetics became available that at least equalled cotton and wool in all properties, which is far from true today, it is unlikely that they would be completely victorious in price competition. Wool still would be produced, even at drastically

lowered prices, as a byproduct of a sheep production for meat. With cotton, there is evidence that large quantities can be produced in this country at a price considerably lower than any foreseeable price to which synthetic fibers might fall, considering the cost of possible raw materials and probable manufacturing costs.

Of course, the extent to which cotton and wool will be displaced by synthetic fibers depends upon a number of factors. If the general level of fiber consumption is high, it can be expected that competition of the synthetic fibers will be less heavily felt, at least for a time, than if the general level of consumption is low. With this qualification, the extent to which cotton and wool will be displaced by synthetic fibers will depend, to a greater extent in the future than in the past, upon which type gives a greater value per unit of cost. With synthetic fibers becoming suitable for more and more uses, they offer increasing numbers of textile users an alternative to the natural fibers that will be selected if it affords a greater value. Price is only one of the factors here involved, physical properties being the other. Both price and physical properties can be influenced by research aimed at an improved product and less costly production and processing methods. At least part of the outcome in the battle between natural and synthetic fibers will depend upon the relative attention given to research on the two types of materials. The relative attention given to merchandising each type of material will also be highly important.

In the preceding paragraphs, attention has been given to some of the factors involved in the long-time outlook for synthetic fibers. For the immediate post-war future, a continued increase in the domestic production of rayon and other synthetic fibers may be expected on the basis of plans already being carried out by manufacturers. 15/ As mentioned earlier in the report, the present war has hastened the large-scale production of high-tenacity rayon, and there is little doubt that there will be increased use of this product in industrial and other textiles in the post-war period. The immediate post-war future will also see the real entrance of nylon and possibly other new synthetic fibers into ordinary textile use, following their release from wartime restrictions.

SUMMARY

Rayon manufacture has been one of the world's most rapidly growing industries since the first World War. World production of rayon increased at an average rate of 32 percent per year during the period of 1920 through 1929 and 17 percent from 1930 through 1940. In 1920, world production of rayon was only about 33 million pounds, but by 1940 this quantity had increased more than seventyfold, to 2,381 million pounds.

15/ See page 41 for discussion of some of the factors in the post-war outlook for synthetic fibers abroad.

World production is reported to have increased still further, to a peak of 3,473 million pounds, in 1942, but to have declined since then because of the war. In the United States, production totaled 663 million pounds in 1943, as compared with 10 million pounds in 1920 and 126 million pounds in 1930.

The rapid increases in the production of rayon in countries such as the United States and Great Britain have been the result of a natural expansion in the use of a new textile fiber. In Germany, Japan, and Italy, on the other hand, production of rayon was increased tremendously during the years immediately preceding World War II by governmental policies designed to increase the use of synthetic fibers, in the place of natural fibers, which would have to be imported.

One of the outstanding developments during the past few years in the field of synthetic fibers has been the sharply increased production and use of rayon staple fiber. From 1931 to 1942, world production increased from 8 million to a reported 2,026 million pounds, while production in the United States increased from less than 1 million pounds in 1931 to 81 million pounds in 1940 and to 162 million pounds in 1943. Staple fiber comprised a reported 58 percent of the world rayon production in 1942 and 24 percent of the United States production in 1943.

Further expansion in the use of rayon during the next few years may be expected, although the extent of these gains cannot be accurately predicted. Although the percentage rate of increase in rayon production from year to year in the United States and in the world is no longer so great as in the early years of the industry, actual year-to-year increases have been larger during the last few years than at any previous time. Despite these increases, rayon now comprises only about 10 percent of the total quantity of cotton, wool, rayon, and silk consumed in the United States, as compared with about 80 percent for cotton, 9 percent for wool, and 1 percent for silk (average 1939-43). Much of the future of rayon will depend, of course upon improvements in its properties and upon its price. In view of such recent developments as high-tenacity rayon and rayon tow, there are no indications that the technological progress of the industry has slackened. Despite wartime rises in prices in general, rayon prices have either remained at pre-war levels or have declined slightly, and there are indications that further reductions in rayon prices are possible in the post-war period.

The basic material used in the manufacture of rayon is cellulose, which is obtained for this purpose from special grades of wood pulp (chiefly from spruce, western hemlock, and southern pine) and from cotton linters. In the United States, percentages of wood pulp and linters used in rayon have shifted considerably in the last ten years, purified linters supplying only 16 percent of the total requirements in 1943 as compared with 46 percent in 1933. Among the causes of this

shift have been continued improvements in the quality of wood pulp, making possible its use in additional types of rayon, and the fact that wood pulp is available at a lower cost than cellulose obtained from linters. Despite its loss of importance percentagewise, consumption of linters in rayon manufacture has not declined on a poundage basis, and it is still regarded as having certain advantages over wood pulp as a source of cellulose for high-tenacity viscose rayon and for rayon made by the acetate and cuprammonium processes.

The first commercially produced rayon was weak, glossy, and highly irregular and was used mostly as a substitute for silk in cheap fabrics or for decorative purposes in mixture with other fibers. Modern rayon is made with varying degrees of luster, is much stronger in both the dry and the wet state, and is more uniform in all its properties. At the same time that these improvements in quality were being effected, its price was being reduced. These improvements in quality and reductions in price have, of course, been major factors in the greatly expanded use of rayon that has occurred during the past ten or fifteen years.

The tremendous expansion in the use of rayon, up to the present, has been predominantly into apparel (particularly women's) and household goods, in fabrics where appearance is the factor of major importance. Recently, however, the development of high-strength types of rayon has made possible the expansion of rayon into such uses as parachutes and military vehicle and airplane tires, where a comparatively high tensile strength is required. Although consumption of rayon continues to increase rapidly, its field of expansion, with its present properties, has definite limits. For instance, in uses where durability combined with low price are the factors of greatest importance, rayon is not at present able to compete successfully with cotton, and much of the field now supplied by cotton comes under this classification. Although considerable quantities of rayon (of the staple fiber type) are now used in mixtures with wool, it does not possess resilience and wearing qualities comparable with those of the better grades of wool, and consequently the potential expansion of rayon into the field now being supplied by wool is also limited. Rayon is a textile fiber with definite and distinct properties, which in some uses offer advantages over cotton, silk, and wool and in others definitely restrict its usefulness.

Other synthetic fibers now in commercial production in the United States are nylon, Vinyon, Vinyon E, and saran, all made from synthetic resins, and casein fiber and glass fiber. Nylon, first announced in 1938, is now used in larger quantities than any other fiber in this group. It is noteworthy for its high strength and elasticity, and has been used successfully in women's hosiery, parachutes, glider tow ropes, airplane tires, and other applications. Vinyon and saran, which have been produced in only limited quantities, are outstanding in their resistance to acids and alkalies. Most important use of Vinyon is for filter cloths; the principal present

use of saran is for window screens. Vinyon E, a recently introduced special type of Vinyon, has unusually high elasticity and is finding some use in elastic yarns. Casein fiber, introduced commercially in the United States in 1940, possesses many chemical properties similar to wool, but in its present stage of development it is inferior, physically, to natural wool. Up to the present, it has been used almost entirely for blending with rayon, cotton, wool, and fur. Glass fibers are outstanding in their ability to withstand high temperatures with little or no damage and also in their resistance to many of the chemicals that are injurious to other textiles. Since all those new fibers are comparatively recent developments, any estimate of their future is highly speculative, but there is little question that at least some of them will find increasingly important places in the textile field.

In general, the synthetic fibers in commercial production today have found uses in many, but not all, types of textiles. They have many properties distinctly different from those of the natural fibers, making them better suited for some uses but definitely less suited for others.

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